Phosphorus and nitrogen in the Al-Hawizeh marshes, southern Iraq

by

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A thesis

presented to the University of Waterloo

in fulfillment of the

thesis requirement for the degree of

Master of Science

in

Biology

Waterloo, Ontario, Canada, 2008

Author’s Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Sama S. Mahamed

Abstract

Hour Al-Hawizeh is one of the biggest marshes within the Mesopotamian marshes of southern Iraq. This Hour has been functioned for centuries under natural conditions providing resources for local people, important habitat for migrating birds, and a major source of the natural hydrology in the Middle East. In the early 1990's, the Mesopotamian marshes were intentionally drained. This disaster has adversely affected the biodiversity of the marshes. In April 2003, these marshes were inundated again with the hope that this ecosystem will return to its previous nature. This new condition led many of scientist and researchers to investigate how the ecosystem behaves after being re-flooded and to assess the restoration progress of these re-flooded areas. In this study, I focused on phosphorus (P) and nitrogen (N), as they are two of the commonly limiting factors for the health of any aquatic system. The main goals of this study are: 1) to determine the TP and TN budget in relation to the water budget of Hour Al-Hawizeh and examine how the water inlets contribute the water supply and nutrient load and determine whether Hour Al-Hawizeh acts as a sink or a source of P and N, whether this varies among sections of the marsh with different flooding histories, and its consequences for the restoration of the marsh, 2) to investigate the TP and TN variation and composition in eight marshes within Hour Al-Hewaizah and investigate the relationship of the phytoplankton component, as indicated by chlorophyll-*a*, with TN and TP concentrations in Hour Al-Hawizeh.

TP and TN budgets suggested that Hour Al-Hawizeh acts as a sink for phosphorus and source for nitrogen. In this study, the annual retention of TP was approximately 128 tons, while annual

release of TN was 237 tons. TP and TN concentration within the eight marshes within Hour Al-Hawizeh exhibited different seasonal patterns during the study period, which is likely attributable to with the variable sources and transformations of phosphorus and nitrogen in the selected marshes. In addition, the study revealed a significant relationship between chlorophyll-*a* concentration and TP and TN. However, the relationship between chlorophyll-*a* and TN was stronger. The differences in water quality parameters, TP, TN, and chlorophyll-*a* concentration between the marshes within Hour Al-Hawizeh suggest that Hour Al-Hawizeh is not a one homogeneous system and each marsh acts as a unique system.

Acknowledgements

It was a challenge for me from the beginning to accept the idea of studying abroad especially when I have been part of a strict culture. However, because of the sense of adventure in my personality, I agreed to take this experience on my own responsibility. During my academic journey as a student, I met many people who made my journey easy and useful. All of them left nice memories in my heart. I would like to thank everyone who encouraged, helped, supported, and prayed for me. I also would like to thank all my friends who made me laugh and made my journey much easier. I would like to thank my supervisor Dr. B. Warner and my committee members Dr. W. Taylor, Dr. R. Aravena, and Dr. A. Douabul, who believed in me and supported me. I would like to thank the Canadian International Development Agency who sponsored me and gave me the opportunity to study in Canada. My grateful thanks to my professor and friend Dr. Jamal Al-Abaychi.

I am truly thankful for the help of my Iraqi field team, who helped me in the field. Many thanks to Sheikh Mohamed Al-Ebadi who supervised field logistics and security. I would like to thank my laboratory team and technicians. Many thanks to Mustafa Al-Juburi how helped me organize my data electronically and my lovely sister-in-law Zainab Al-Yawer.

I want to say thanks to Dr. Ralph Smith, Dr. Roland Hall, Dr. Taro Assada, Richard Elgood, William Mark, Yuri Kozlov, and all my friends in UWAGE: Victoria S. Jackson, Ann M. Balasubramaniam, Mohamed Mohamed, Jennifer Hood, Megan Puchniak, Dave Depew, Sindy

Wang, Sairah Malkin, and Louise Chavari who has encouraged, assisted, and advised me during the work.

I would like to thank my family, my mom, dad, and young sister; I want to tell them how much I appreciate them. They believe in me and they know that even if I am alone I can finish the job and be what they always want me to be.

Dedication

I dedicate this work to my twin spirit

Ari,

Far across the distance
And spaces between us
You have come to show you go on

Near, far, wherever you are
I believe that the heart does go on
Once more you open the door
And you're here in my heart
And my heart will go on and on

"James Horner, Will Jennings"

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Chapter 1

Introduction

1.1 The importance of nutrients in wetlands

Nutrients are essential for healthy aquatic systems (Cornelisse & Evans, 1999; Moore, 2001). Phosphorus (P) and nitrogen (N) are two of the most important nutrients for plant growth (Van Der Valk, 1989; Evans, 1994; Mitsch & Gosselink, 2000; Moore, 2001; Wetzel, 2001; Van Der Valk, 2006). Their availability often controls primary productivity, and influences the diversity of aquatic organisms (Evans, 1994; Batzer & Sharitz, 2006). On the other hand, P and N can be in excess to the detriment of biodiversity and water quality so their concentrations are also very important from that perspective (Evans, 1994). Their dynamics are considered important factors in the assessment of the biological and geochemical activities of wetlands (Evans, 1994). P and N concentrations can reflect the ecological status of damaged wetlands because they provide information on the resilience of restored ecosystems (Marion & Brient, 1998; Annadotter *et al*., 1999; Comin *et al*., 2001; Moore, 2001; Ruiz-Jaen & Mitchell, 2005).

The importance of P and N in wetlands has been thoroughly discussed in different ways. For example, many studies have focused on the estimation of P and N budgets, which help to put different sources in context (Birch & Spyridakis, 1981; Hillbricht-Illkowska, 1993; Yanagi, 1999; Krah *et al*., 2006; Moosmann *et al*., 2006); other studies have used P and N dynamics to assess wetland restoration (Hambright *et al*., 1998; Zohary *et al*., 1998; Fustec *et al*., 1999; Gophen, 2000; Ghliem, 2001; Braskerud, 2002; Reinhardt *et al*., 2005; Ruiz-Jaen & Mitchell, 2005; Richardson *et al*., 2005; Richardson & Hussain, 2006). Some studies used the efficiency of

P and N concentrations to evaluate the water quality of natural and damaged wetlands (Van Geldermalsen, 1985; Benson-Evans *et al*., 1999; Hillbricht-Illkowska & Wioeniewiski, 1993; Okbah, 2005; Peder *et al*., 2006; Panigrahi *et al.*, 2007); and others used P and N variation as a management tool for many constructed and damaged wetlands (Wetzel, 2001; Ruiz-Jaen & Mitchell, 2005; Richardson & Hussain, 2005).

1.2 Phosphorus and nitrogen sources and cycles

The main sources of nutrients can be either from point or non-point sources (USEPA, 2007). Point sources can be a municipal wastewater treatment plant or industrial wastewater outlets. Non-point sources include agricultural (cattle manure and fertilizer), resource extraction (mining and soil erosion) or/and other natural sources (atmospheric deposition, precipitation, groundwater input (McDowell & Watkins, 2004; USEPA, 2007).

The P and N cycles are two of the most important biochemical cycles of wetlands and are controlled by physical, chemical, and biological processes in the water and sediment (Van Der Valk, 1989; Mitsch & Gosselink, 2000; Moore, 2001; Wetzel, 2001). P and N cycles have been described from different approaches (Horne & Goldman, 1983; Van Der Valk, 1989; Mitsch & Gosselink, 2000; Wetzel, 2001; Van Der Valk, 2006). Horne & Goldman (1983) discuss P and N sources and describe the most important biochemical processes that influenced with their cycles. They also have established the principles of P and N uptake and re-cycling. Mitsch & Gosselink (2000) explain the processes of P and N transformations in wetlands. Batzer & Sharitz (2006) comprehensively describe the biogeochemical processes that interact with P and N dynamics in temporary wetlands.

P cycle in wetlands is regulated by three main factors: (1) physical factors such as sedimentation and entrainment; (2) chemical factors such as precipitation; and (3) biological mechanisms such as uptake and release by plants (Horne & Goldman, 1983). P occurs in water in both organic (OP) and inorganic (IP) forms, and these forms can be dissolved (DIP, DOP) or particulate (PIP, POP). Orthophosphate (PO_4^-) is the dominant DIP and it is the essential fraction for plant uptake (Horne & Goldman, 1983; Mitsch & Gosselink, 2000). In many wetlands, DOP comes mainly from the decomposition of dead organisms and can be broken down via enzymes or by UV light. Algae and bacteria can produce *alkaline phosphatase*, which has the ability to hydrolyze PO_4^- from many forms of DOP (Horne & Goldman, 1983). Most P is associated with algal and bacterial cell wells. P compounds can be adsorbed on soil particles such as clay (Horne & Goldman, 1983). Different chemical reactions move P in the aqueous phase between PO_4^- and DIP (Figure 1). Bacteria can also convert PO_4^- or DOP to POP and vice versa (Horne & Goldman, 1983; Figure 1). P cycling in wetlands is relatively balanced in that DP and PP vary relatively slowly but several factors contribute to low concentrations of P in most freshwater bodies (Mitsch & Gosselink, 2000), including that there is no gaseous phase in the atmosphere that can diffuse into water when P is exhausted, and particulate phosphorus is sometimes refractory or has a slow decomposition rate (Horne & Goldman, 1983).

N is also has organic and inorganic forms, which can be found as dissolved (DIN, DON) and particulate (PIN, PON). The most common DIN species are ammonium (NH_4^+), nitrate (NO_3^-), nitrite (NO_2^-), and urea CO $[NH_2]_2$. NH_4^+. Plants take NH_4^+ first and then NO_3^- because NO_3^- requires more chemical energy to be reduced and incorporated into organic molecules (Horne & Goldman, 1983). NH_4^+ concentration is often very low in water because it is in demand for uptake and it can easily be oxidized by nitrify (Horne & Goldman, 1983). NO_3^- is the oxidized form of DIN, which can be transformed into NH_4^+ through biological assimilation followed by re-mineralization (Figure 2). In contrast to NO_3^-, NO_2^- concentration is considerably lower in water. Organic N can be added to the aquatic system during the partial decomposition of dead organisms (Figure 2).

The most important biochemical transformation processes that control the N cycle are *N-fixation*, *nitrification* and *denitrification* (Figure 2). Specific conditions, e.g. anoxic environments and presence of enzymes (Horne & Goldman, 1983), govern these processes. N-fixation occurs in some species of bacteria and blue-green algae; through this process, gaseous nitrogen (N_2) is assimilated and reduced into organic molecules (Figure 2). Denitrification is a chemical reaction that occurs in bacteria. Denitrifying bacteria are able to transform NO_3^- into N_2. Nitrifying bacteria can oxidize NH_4^+ to NO_3^- in order to obtain energy, and this process called *nitrification* (Figure 2).

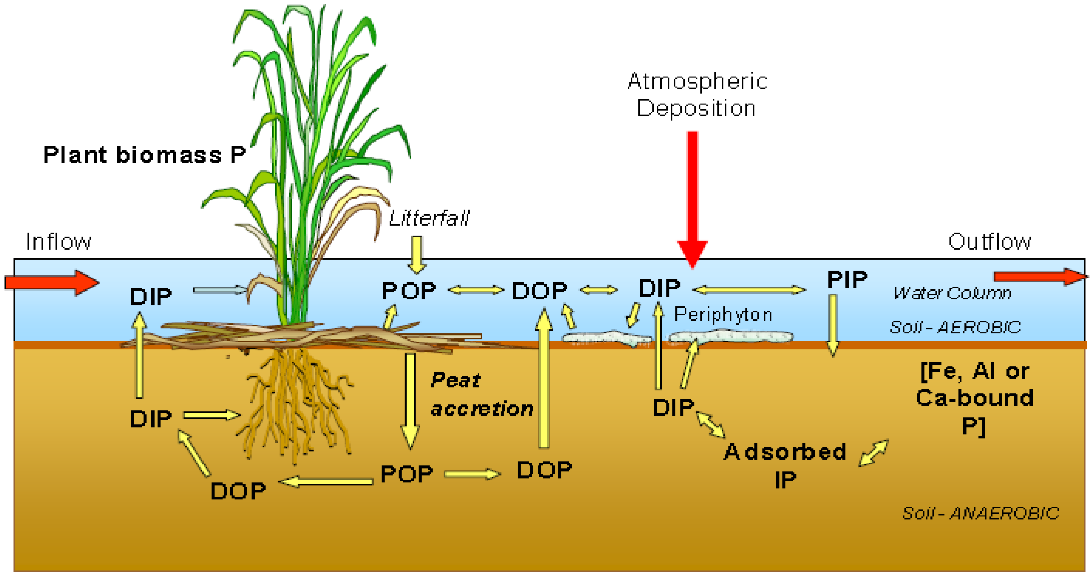


Figure 1: Phosphorus cycle and the main transformations in the water column and sediment in wetlands. Photo adapted from USEPA, 2007.

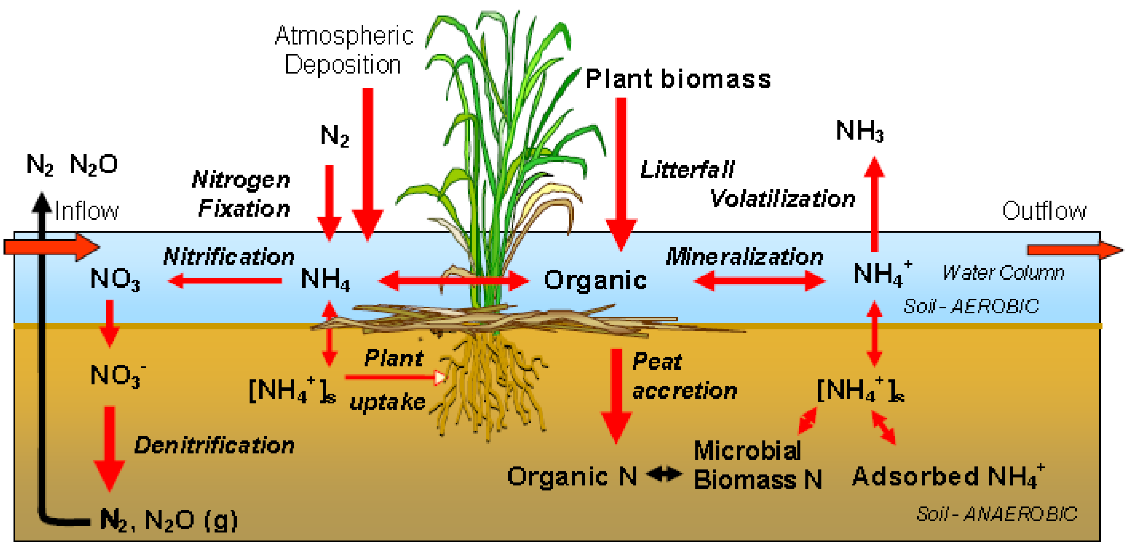


Figure 2: Nitrogen cycle and the main biological processes that occur in the water column and sediment in most wetlands. Photo adapted from USEPA, 2007.

1.3 Phosphorus and nitrogen in wetlands

P and N dynamics in wetlands have been discussed by Van Der Valk (1989), Evans (1994), Marion & Brient (1998), Annadotter *et al*. (1999), Cornelisse & Evans (1999), Mitsch & Gosselink (2000), Comin *et al*. (2001), Moore (2001), Wetzel (2001), Ruiz-Jaen & Mitchell (2005), Batzer & Sharitz (2006), and Van Der Valk (2006). The seasonal variations of P and N concentrations, especially in the water, tend to have different patterns depending on the location of the wetlands (Horne & Goldman, 1983; Van Der Valk, 1989; Mitsch & Gosselink, 2000; USEPA, 2007). The seasonal pattern of P and N in most sub polar and tropical wetlands is uni-modal (Birch &.Spyridakis, 1981; Benson-Evans, 1999; Hambright *et al*., 1998; Gophen, 2000), while the seasonal pattern of P and N in most of the temperate and sub tropical wetlands (including the Mesopotamian marshes) is bi-modal (Maulood *et al.*, 1979; Maulood *et al.*, 1981; Al-Saadi & Al-Mousawi, 1988; Al-Zubaidi, 1985; Qassim, 1986; Al-Lami, 1986; Al-Araji, 1988; Hassan, 1988; Al-Rikaby, 1992; Alwan, 1992). Previous studies on the Mesopotamian marshes indicated that the first growing season in Iraq begins in spring, when algae and macrophytes start growing intensively, and ends in early summer due to the temperature increase (30 °C). The second growing season starts in early fall when the temperature drops down a little bit (25 °C) and ends in early winter (Al-Mousawi & Hussain, 1992; Alwan, 1992).

The production and consumption of P and N in wetlands are the major factors that control the fluctuation of these nutrients in the water column. Macrophytes, phytoplankton, and seston utilization and decomposition are likely the main factors that determine the availability of the P and N species in the aquatic systems (Hambright *et al.*, 1998). Several studies have found a relationship between phytoplankton biomass, algae blooms, chlorophyll-*a* concentrations, and net productivity with the TP and TN (Benson-Evans, 1999; Zohary, 1998; Radwan, 2005).

Decreases of DIP and DIN are likely due to uptake (Birch & Spyridakis, 1981; Van Geldermalsen, 1985; Al-Araji, 1988; Hassan, 1988), while increases of DP and DN are likely due to decomposition (Birch &.Spyridakis, 1981; Okbah, 2005). Macrophytes, periphyton, and phytoplankton are responsible for removal of most DIP and DIN, especially during the growing season (Birch & Spyridakis, 1981; Hambiright *et al.*, 1998; Gophen 2000; Okbah, 2005). However, sedimentation is an alternative path for PP and PN removal (Van Geldermalsen, 1985; Birch & Spyridakis, 1981; Gophen, 2000).

The availability of P and N in wetlands can be affected by several physical and chemical parameters such as water temperature, dissolved oxygen, pH, and pollutants (Panigrahi *et al*., 2007). Some of these variables were measured in order to find their impact on the ecological characteristics of the wetlands systems (Panigrahi *et al*., 2007). For example, the concentration of dissolved oxygen in the sediment can influence mineralization of N in wetlands and the amount of DIN in the water column. On the other hand, the increase of water temperature enhances the denitrification processes in the sediment (Birch & Spyridakis, 1981; Van Geldermalsen, 1985). Pollutants such as agricultural pesticides, industrial wastewater, and domestic wastewater likely have a negative impact on P and N dynamics in wetlands and thus affect the ecological behavior of the aquatic habitat (Al-Araji, 1988; Hassan, 1988; Radwan, 2005; Panigrahi *et al*., 2007).

1.4 Phosphorus and nitrogen limitation

There are large bodies of literatures on the geochemical and ecological features that can influence the nature of P and N in specific aquatic environments (Vitousek & Howarth 1991). Nutrient limitation is one of the most common subjects that many ecologists focus on because it helps them to understand the control of biomass and productivity in aquatic ecosystems (Redfield, 1958; Elser *et al*,. 1990).

In fresh water, redox-dependent P retention in sediments, de-nitrification versus N fixation and food web structure can affect the P and N supply and thus limit their availability (Elser *et al.*, 2007; Figure 3). On the other hand, excess loading of P and N can impair the function of the aquatic ecosystem and reduce their biological diversity and ecosystem functioning (Hecky & Kilham, 1988; Elser *et al.*, 1990; Elser *et al.*, 2007).

Most freshwater wetlands are usually P limited (Vitousek & Howarth, 1991; Zohary, 1998; Gophen, 2000; Krah, 2006), while N is the primary limiting nutrient in marine ecosystems (Redfield, 1958; Elser *et al.*, 2007; Panigrahi *et al.*, 2007). In some freshwater wetlands, N can be both a primary and a secondary limiting nutrient as it found in Lake Tahoe in California (Elser *et al.*, 1990). Although the Mesopotamian marshes are fresh water wetlands, previous studies on the Mesopotamian marshes indicate that these marshes are N limited (Al-Mousawi & Hussain, 1992).

Relief of

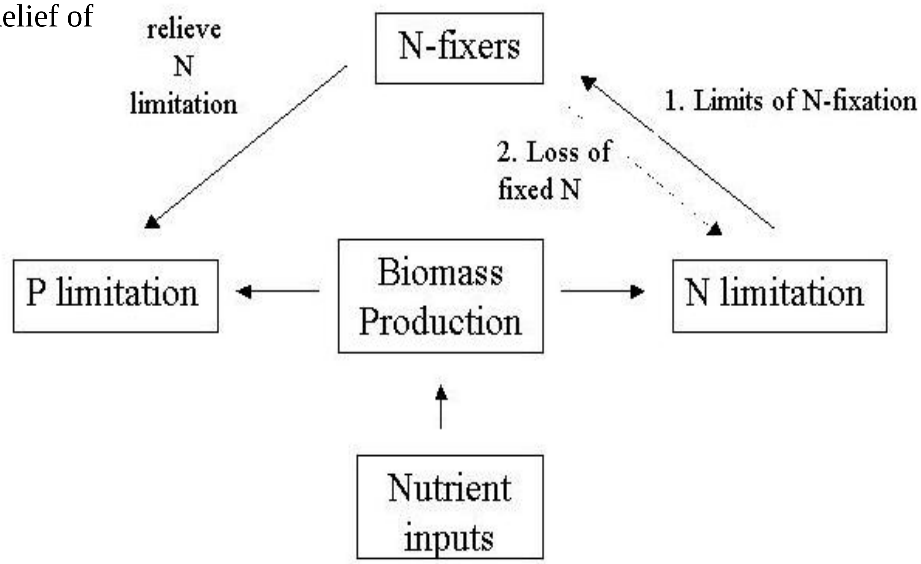


Figure 3: The main factors influencing phosphorus versus nitrogen limitation in most aquatic systems. Graph adapted from Wetzel, 2001.

1.5 The importance of studying phosphorus and nitrogen in the Mesopotamian marshes

The natural condition of the Mesopotamian marshes, before the 1990's when these marshes were dried and destroyed by several anthropogenic impacts, was studied intensively from different ecological aspects. Hussain (1992) reviewed most of the Mesopotamian studies from early 1970 until 1990. The recent studies, which represent the period after April 2003 when the marshes re-flooded again, focus on studying and investigating the newly re-flooded system in order to assess the restoration process of the Mesopotamian marshes. Different environmental aspects, including hydrology, biological productivity, biogeochemical cycling, and wildlife habitat, were intensively studied (Richardson *et al.*, 2005; Al-Imarah *et al.*, 2006; Richardson & Hussain, 2006; USAID, 2006; Tahir *et. al.*, 2008). Richardson & Hussain (2006) and USAID (2006) used the Ecosystem Functional Assessment (EFA) method to evaluate the restoration process of newly re-flooded marshes within the Mesopotamian marshes. Al-Imarah *et al*. (2006) and Tahir *et al.* (2008) focused on comparing the new condition of the re-flooded marshes with the previous natural conditions. In this study, P and N concentration, speciation, and budget will be examined in one of the biggest marshes within the Mesopotamian marshes, Hour Al-Hawizeh, after being re-flooded. In addition, this study will provide valuable baseline information and will assess how parts of the ecosystem with different flooding histories function with present to nutrients.

1.6 The Mesopotamian marshes

The Mesopotamian marshes or Ahwar region (Ahwar is plural, Hour is singular) are located in the lower basins of the Tigris and Euphrates Rivers in Iraq (Figure 4). This unique ecosystem historically was the largest marsh system in the Middle East (Scott, 1995; Partow, 2001; IMET, 2006) and one of the most important wetlands in the world (Partow, 2001; IMET, 2006). It is important to have a clear picture of the evolution, hydrology, habitat biodiversity, and socioeconomics of these marshes. Such detailed information will help to understand the nature of this unique ecosystem.

1.6.1 The evolution of the Mesopotamian marshes

The Mesopotamian marshes occupied an area variously represented as between 10,000 km^2 and 20,000 km^2 (Willi, 1992; Scott, 1995), extending between 29°55’ and 32°45’ N to 45°25’ and 48°30’ E. The Mesopotamian marshes are complex and diverse aquatic systems, and mostly extensive areas of emergent macrophytes and shallow open waters. These marshes are divided into three main areas: the Al-Hammar marsh in the west, the Central marshes, and Al-Hawizeh marsh in the east (Figure 4). These unique ecosystems sustain large number of important habitats (IMWR-CRIM, 2006). They seasonally support many international migratory birds (Scott, 1995; Partow, 2001; IMWR-CRIM, 2006; USAID, 2006) and maintain huge populations of wildlife including endemic and endangered species (Scott, 1995; USAID, 2006). For humans, they provide resources such as fisheries and building materials (Scott, 1995; USAID, 2006).

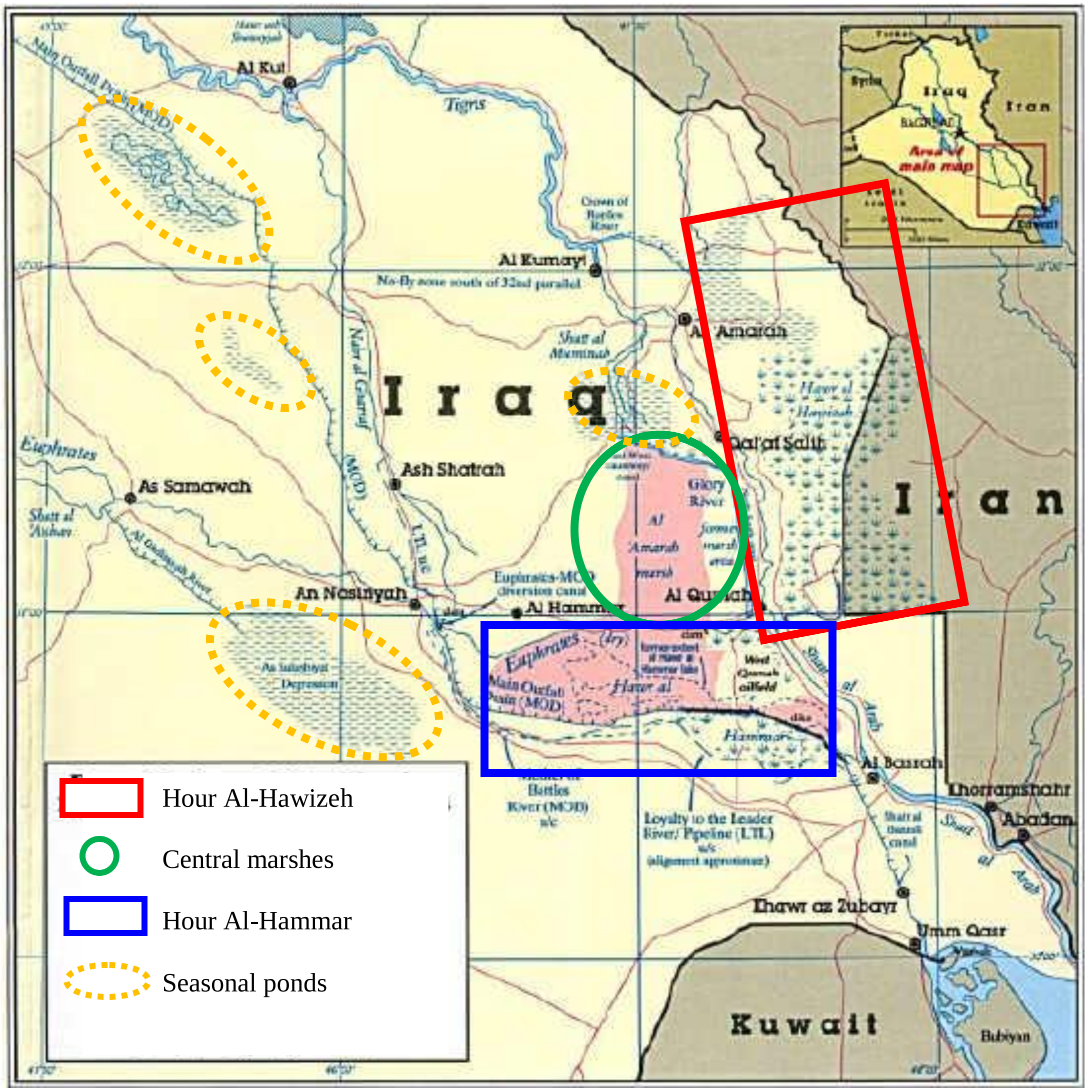


Figure 4: The three main marshlands and the seasonal ponds within the Mesopotamia marshlands. Graph adapted from USCIA, 1994.

The history of the Mesopotamian marshes goes back to the 4000 BC (Scott, 1995). Different paleo-geological studies have been done to investigate the initiation of this area (Lees & Falcon, 1952; Larsen, 1975; Aqrawi, 1992; Al-Sakini, 1992). These studies report that the Arab Gulf waters once covered the lower Tigris and Euphrates basins of the Iraq, and the recession of the Arab Gulf in approximately 5000 BC was the main reason for the creation of the Mesopotamian marshes. The marine wetlands became freshwater as they drained (Al-Sakini, 1992).

1.6.2 The water sources of the Mesopotamian marshes

The main water sources of the Mesopotamian marshes are the Tigris and Euphrates rivers (Willi, 1992). The sources of the Tigris and Euphrates are located in the northeastern part of Turkey (Partow, 2001). The Euphrates begins at Mount Ararat near Lake Van, while the Tigris originates from Lake of Hazar (Partow, 2001). The Euphrates flows from Turkey through Syria into Iraq, while Tigris flows from Turkey into Iraq. The two rivers continue flowing in the Iraqi territories until they joined in Al-Qurna City in southern Iraq (Rzóska, 1980; Talling, 1980).The plentiful snowmelt and heavy rainfall that occur in the mountains around Turkey, Syria, Iraq, and Iran provide strong water pulses into the Tigris and Euphrates (Rzóska, 1980; Talling, 1980). Precipitation is also a source of water to the marshes. However, it supply is relatively less than the main rivers. The average annual rainfall in the marshes is less than 200 mm (Maulood *et al*., 1981).

1.6.3 The socioeconomic and habitat biodiversity of the Mesopotamian marshes

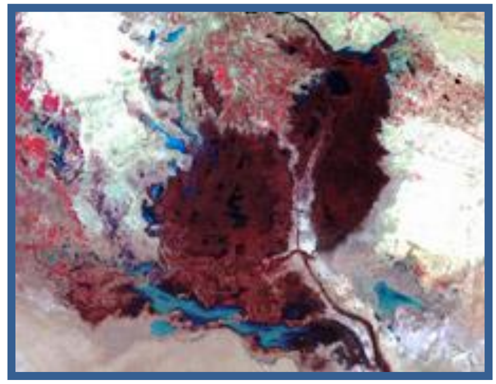
The Mesopotamian marshes are thought to be the subject of the legend of the Garden of Eden (Scott, 1995). This fabulous land has sustained large and strong civilizations such as Ur and Babylon (Scott, 1995). The ancient human population, now called Al- Ma’dan or Marsh Arabs, depends on the marshes for resources and habitat. Although people in various areas within Iraq changed their lifestyle, the Mesopotamian dwellers never changed their traditional way of life (Scott, 1995). Their local economy depends strongly on reeds, water buffalo, fishing, and mat weaving. Agricultural activity is an important aspect of the Mesopotamian marshes economy. Rice and wheat are the most commonly grown plants in the marshes, especially at the marshes edges. The Mesopotamian marshes sustain fauna and flora adapted to that aquatic system (Scott, 1995). For instance, the most common plant species these marshes is *Phragmites australis*. The Mesopotamian dwellers used reeds for centuries to build their houses and to feed their cows and water buffaloes. The marshes are also one of the important resting places for migrating birds from Northern Europe and Asia (Scott, 1995). The land provides the suitable thick plant cover that allows birds to rest, feed, and breed. These marshes also maintain great populations of freshwater fish species by providing spawning grounds, nurseries, and feeding places. Besides that, the Mesopotamian marshes have unique mammal communities like herbivores, including water buffalo, which is the most important economic animal, providing food and fuel. The marshes are also known by their wild animals such as fallow deer, goitered gazelle, wild boar, and otters (Scott, 1995).

1.7 The twentieth century disaster

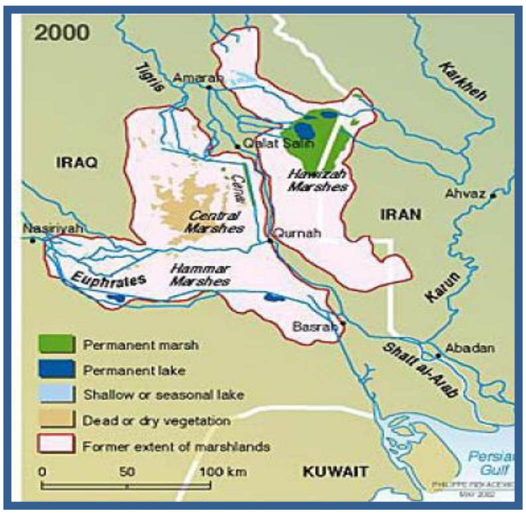
During the twentieth century, the Mesopotamian marshes suffered from several anthropogenic disturbances such as water control, irrigation channels, and wars. These factors negatively influence and destroy this ecosystem (Figure 5). For example, the construction of irrigation channels, dams, and flood relief systems upstream utilizes most of the Tigris and Euphrates waters and thus reduce the water supply into the marshes (Maulood *et. al.*, 1981; Scott, 1995).

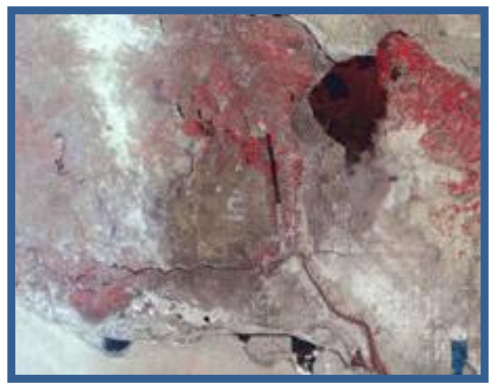
On the other hand, the process of drying the Mesopotamian marshes, which started in the early 1950's, strongly affected the ecological features of this area (Scott, 1995). The Iraqi government wanted to change the marshes to maintain agriculture activities. By the end of 1980, great portions of the marshes were already turned into farmlands. Channels and embankments were built to divert water from the marshes and change the water direction to supply farms (Evans, 1994). Even before the desiccation, The Iraq-Iran war had also a negative impact on the Mesopotamian marshes. They were extensively damaged by heavy bombing and shelling; enormous areas were burned from the use of chemical weapons (Scott, 1995). The Iraqi army also destroyed vast areas with heavy cutting machines and by burning huge areas, especially in the marshes that lay on the border with Iran (Evans, 1994).

The loss of water led to lose nearly 90% of the marshes during the period 1984 to 1999 (Evans, 1994; Scott, 1995), and destroyed of the ecosystem's biodiversity and social communities (Partow, 2001).



Mesopotamian marshlands in 1973





Mesopotamian marshlands in 2000

Figure 5: Two different views of the Mesopotamian marshlands show the extreme changes that happened between 1973 and 2000. The upper picture presents the previous stage of the Mesopotamian marshlands before the desiccation, while the lower picture shows the loss of marshlands after eight years of being dried. Graph adapted from Partow, 2001.

1.8 Hour Al-Hawizeh

The Al-Hawizeh marshes or Hour Al-Hawizeh is the largest marsh system within the Mesopotamian marshes (Willi, 1992). Most of Hour Al-Hawizeh is located between 31° 00’ and 31º45’ N and between 47° 25’ and 47º 50’ E of Iraq. A small part of Hour Al-Hawizeh is situated in Iran (Scott, 1995). The marsh used to occupy an area between 2500 and 3500 Km^2 during the flood season (Scott, 1995; Partow, 2001).

Hour Al-Hawizeh has water sources from Iraq and Iran (Figure 6). The Iraqi inlets are the Al-Mshereh River, the three tributaries of the Al-Kahla River, and seasonal water discharge from Al-Sannaf marsh (Figure 6). The Iranian inlet is the Al-Karkheh River. On the other hand, Hour Al-Hawizeh has two main outlets, the Al-Kassara and Al-Suwayb rivers (Figure 6). Water flows from Al-Kassara River into the Tigris River (Figure 6). Water flows from the Al-Suwayb River into Shatt Al-Arab River (Figure 6). The riverine system of Hour Al-Hawizeh will be discussed in detail in chapter 2.

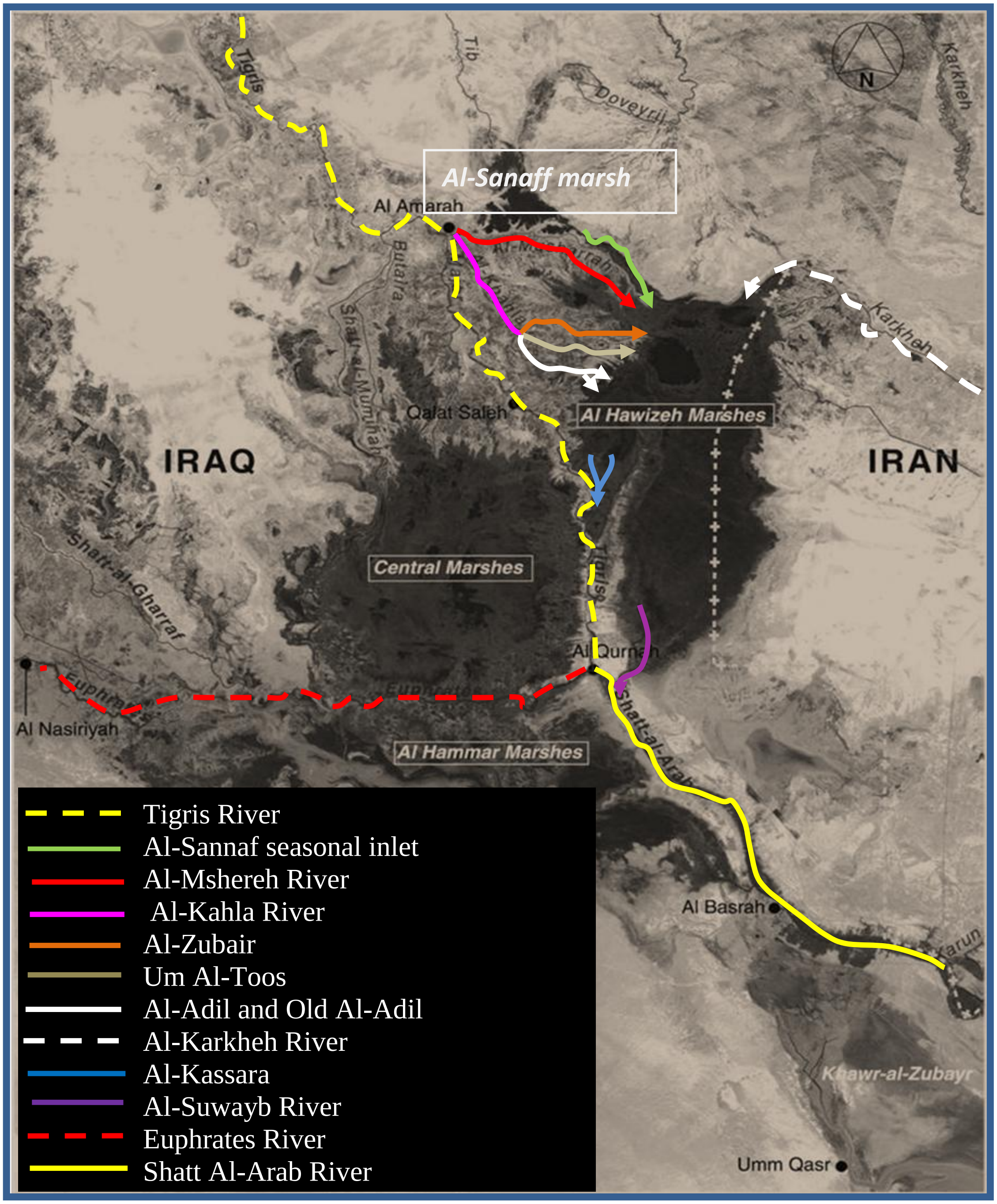


Figure 6: A map description of the riverine inlets and outlets of Hour Al-Hawizeh. Graph adapted from Partow, 2001.

Hour Al-Hawizeh harmfully influenced by the Iraq-Iran war more than the other marshes within the Mesopotamian marshes because it is located on the border between those countries. The roads and embankments, which had built by the Iraqi government to support the soldiers, changed the water movement within the area and thus affect the marshes greatly. Just after the end of the Iraq-Iran war, the Iraqi government started again to complete the drying process and this time the government controlled the amount of the water entering to the marshes and left the area to dry gradually. Fortunately, the north part of Hour Al-Hawizeh was less affected in comparison to the south part because of the water supply from Iran (Scott, 1995; Partow, 2001). The loss of water divided Hour Al-Hawizeh into three distinct areas (Figure 7). The northeast part of Hour Al-Hawizeh remained wet. The central part also retained water, but it became drastically reduced compared to its original size. The southern part dried completely and became a desert (Partow, 2001, IMWR-CRIM, 2006).

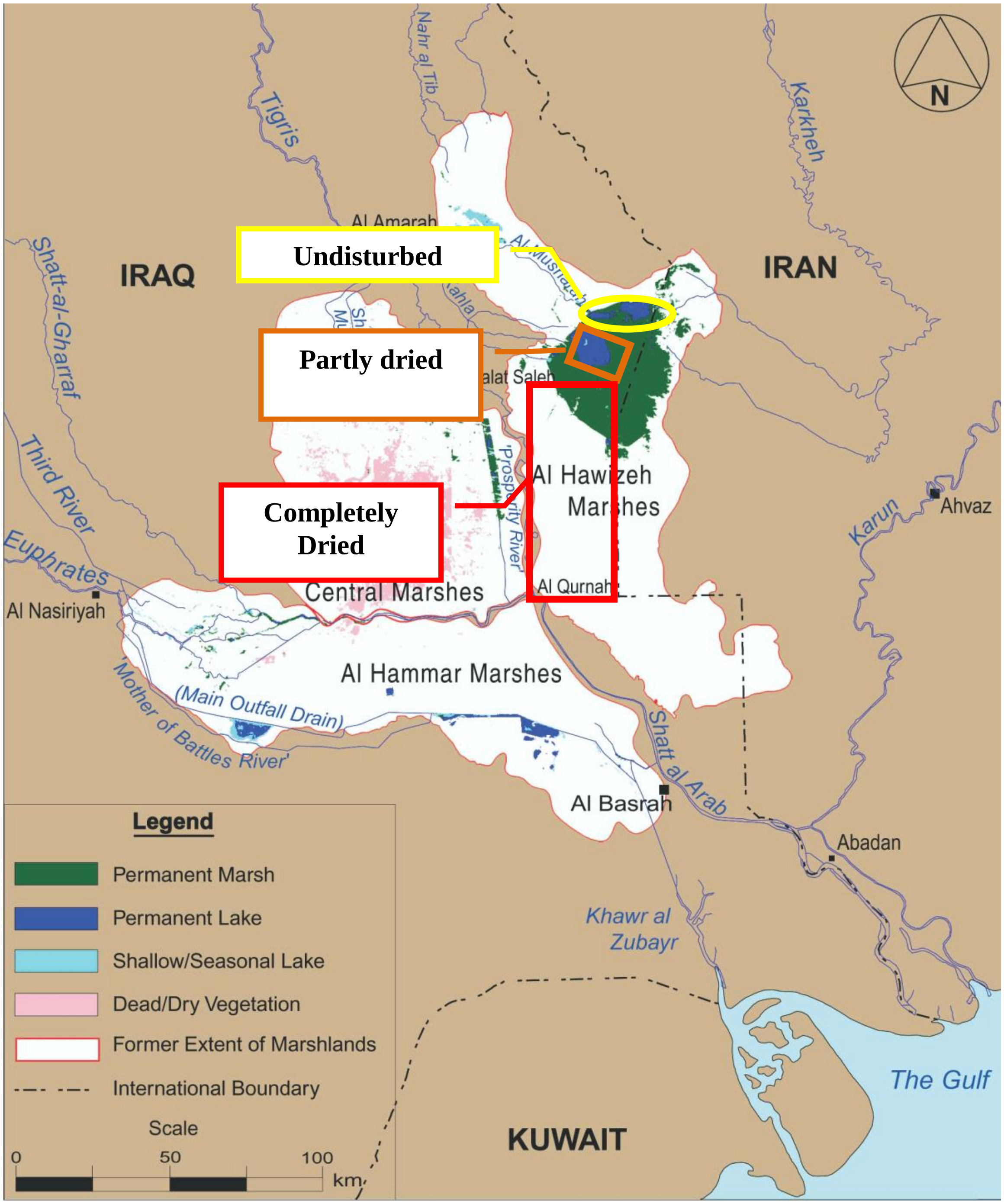


Figure 7: A map of Hour Al-Hawizeh showing the three parts that occurred after the drying process of the Mesopotamia marshlands. Graph adapted from Partow, 2001.

1.9 Objectives

The general aim of this study is to understand how Hour al-Hawizeh is behaving after the re-flooding by focusing on phosphorus and nitrogen because they are two of the commonly limiting factors of the health of any aquatic system. This will help our understanding of whether Hour Al-Hawizeh will be able to return to its previous condition, and how that will affect downstream conditions.

More specifically, this research seeks

1. To determine the TP and TN budget in relation to the water budget of Hour Al-Hawizeh and examine how the water inlets contributes the water supply and nutrient load.
2. To determine whether Hour Al-Hawizeh acts as a sink or a source of P and N, whether this varies among sections of the marsh with different flooding histories, and its consequences for the restoration of the marsh.
3. To investigate the TP and TN variation and composition in eight marshes within Hour Al-Hewaizah.
4. To investigate the relationship of the phytoplankton component, as indicated by chlorophyll-*a*, with TN and TP concentrations in Hour Al-Hawizeh.

Chapter 2

Phosphorus and nitrogen budgets

2.1 Introduction

Understanding nutrient balance in wetlands is one of the keys to help improve damaged ecosystems; however, it requires different kinds of information (Dolan *et al*., 1981; Mukhopadhyay & Smith, 2000). Several methods can be used to estimate nutrient budgets for different aquatic systems (Dolan *et al*., 1981; Mukhopadhyay & Smith, 2000). For example, mass balance and box models that, which been developed for specific types of wetlands, are two of the most common methods (Cole & Fisher, 1979; Birch & Spyridakis, 1981; Yanagi, 1999; Krah *et al*., 2006; Peder *et al.*, 2006). These models have been used to estimate production and respiration processes in wetlands (Cole & Fisher, 1979; Yanagi, 1999), evaluate the efficiency of nutrient recycling (Birch & Spyridakis, 1981), and monitor the restoration processes in damaged wetlands (Peder *et al.*, 2006)

Nutrient load is an ecological term, which has been widely used in many studies (USEPA, 2007). The common definition of nutrient loading is the total amount of nutrient that enters the system during a period of time (USEPA, 2007). The variation of nutrients load entering an aquatic system influences the biological and geochemical activities in the system (Wazniak *et al*., 2004; USEPA, 2007). The differences between nutrient load and export in any aquatic system can be associated with plant uptake and production (USEPA, 2007). When the nutrient load is greater than export then the system functions as a sink for nutrient (Wazniak *et al*., 2004; USEPA, 2007). Aquatic systems can also be sources of nutrient when the nutrient export exceed the load (Wazniak *et al*., 2004; USEPA, 2007).

The methods used to calculate the nutrients budget might be different from one system to the other, depending on the system type, water resources, and mass balance (Dolan *et al.*, 1981; Mukhopadhyay, 2000). However, statisticians and ecologists have modified many standard formulas in order to reach the most suitable model that can be applied to a specific ecosystem (Dolan *et al*., 1981; Mukhopadhyay, 2000). Several nutrient budget models have been developed as tools for water resources management (Birch & Spyridakis, 1981; Dolan *et al*., 1981; Yanagi, 1999; Mukhopadhyay & Smith, 2000; Krah *et al*., 2006; Moosmann *et al*., 2006). These models improve our understanding of the long-term fate of nutrients introduced to aquatic systems (Dolan *et al.*, 1981). It is worth mentioning that no previous studies have been done to estimate nutrient budget of the Mesopotamian marshes (Hussain, 1992). It was a challenge to attempt to estimate the P and N budget in Hour Al-Hawizeh due to hydrological complexity and the fact that it has unmonitored water input from Iran. My work is the first of its kind and should be used in the future as a basis to develop more detailed mathematical models for Iraqi wetlands.

2.2 Study site descriptions

2.2.1 Water resources of Hour Al-Hawizeh

2.2.1.1 Water inlets

As I mentioned in chapter 1, the main Iraqi water inlets are the Al-Mshereh River and the three tributaries of the Al-Kahla River, Al-Zubair, Um Al-Toos, and Al-Husachi (Figure 8). The Al-Mshereh River flows from the Tigris River into the north part of Hour Al-Hawizeh directly passing through Al-Mshereh City (Figure 8). Fifteen irrigation canals and surrounding fields drain water from the Al-Mshereh River into the Al-Sannaf marsh, northern Hour Al-Hawizeh.

The canals reduce the velocity of the water and decrease its discharge into Hour Al-Hawizeh. The Al-Zubair tributary has two main branches that flow into Al-Ma'eel canal (IMWR-CRIM, 2006) which flows directly through set of pipes into northwestern Hour Al-Hawizeh (Figure 8). Its water slightly influenced by untreated domestic water flows from the surrounding villages (Willi, 1992; Partow, 2001). The Um Al-Toos tributary is also influenced by domestic waste from villages located on both riverbanks (Figure 8). These villages are raising considerable numbers of water buffalos and thus affecting the water quality of the river (Partow, 2001). The Al-Husachi tributary flows from the west directly into Hour Al-Hawizeh (Figure 8). It is divided into two branches: Al-Adil and old Al-Adil just 5 Km before entering Hour Al-Hawizeh. The Al-Husachi tributary passes through extensive agricultural fields. The drainage water from these fields enters directly into the river and they are potential source of nutrients from chemical fertilizer (Partow, 2001). On the other hand, Hour Al-Hawizeh receives minor seasonal water discharge from Al-Sannaf marsh (Figure 8) when the water level in Al-Sannaf marsh increases (IMWR-CRIM, 2006). As well, it receives water supply from Iran through the Al-Karkheh River (Figure 8).

2.2.1.2 Rainfall

The climate of the Mesopotamian area is Mediterranean; hot and dry in summer, cold and rainy in winter (AEBS, 2004). The precipitation over the lower part of Iraq starts in December and ends in March (IMWR-CRIM 2006). The average annual precipitation of the southern part of Iraq was less than 200 mm (Maulood & Boney, 1980, Hussain, 1992), and the present average annual rainfall recorded the last twenty years (IMWR-CRIM, 2006).

2.2.1.3 Water outlets

Hour Al-Hawizeh has two main outlets, the Al-Kassara and Al-Suwayb rivers (Figure 8). The Al-Kassara River discharges water from the northern part of Hour Al-Hawizeh into the Tigris River (Figure 8) while the Al-Suwayb River discharges waters from the southern part into the Shatt Al-Arab River (Figure 8).

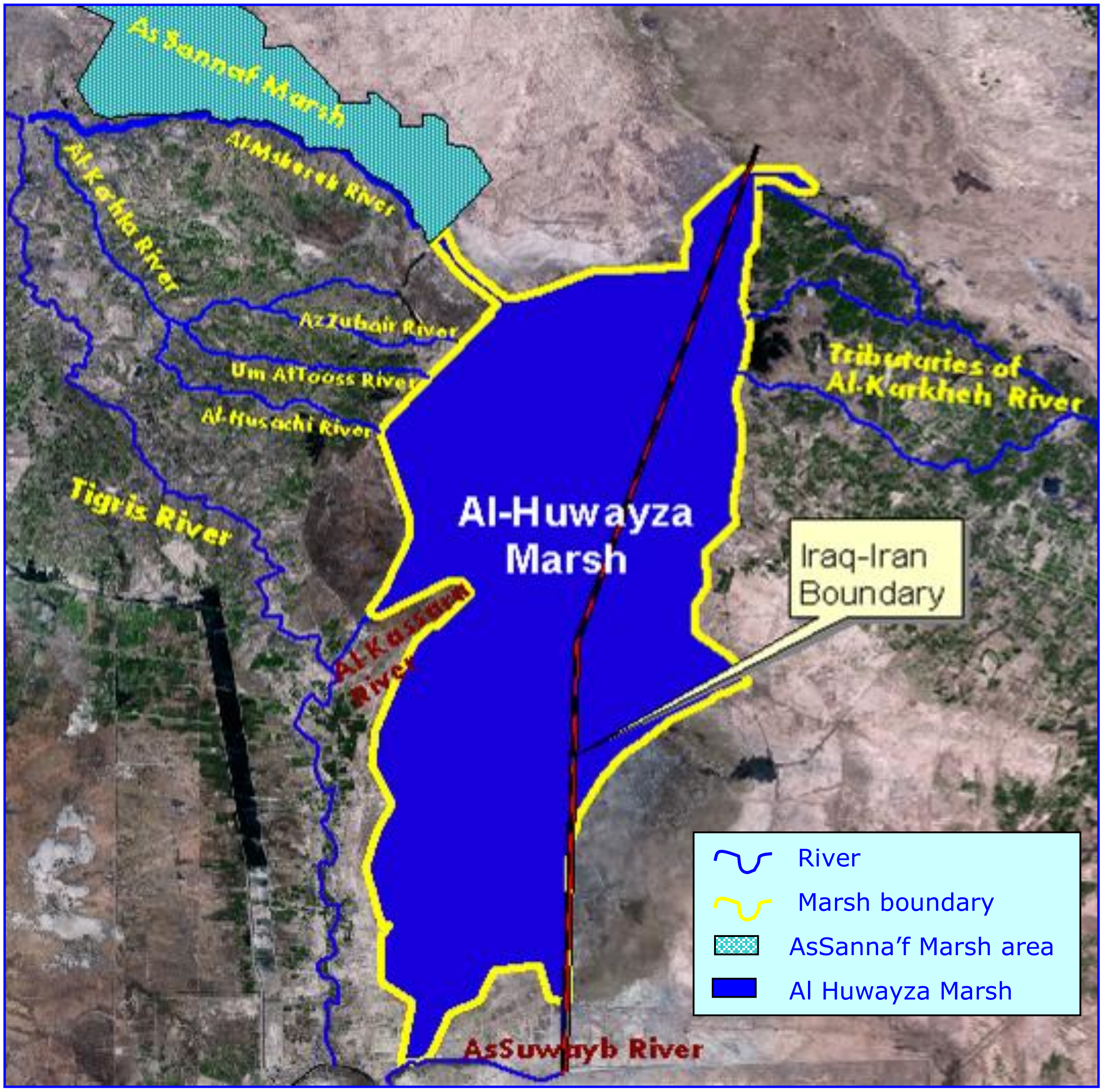


Figure 8: The riverine system of Hour Al-Hawizeh. Graph adapted from IMWR-CRIM, 2006.

2.3 Material and methods

2.3.1 Water discharge data

Monthly water discharge data of the Iraqi rivers (Al-Mshereh, Al-Zubair, Um Al-Tooss, and Al-Husachi rivers) were obtained from the Iraqi Ministry of Water Resources from May 2006 to March 2007. The average annual rainfall from 1987 until 2005, the average evaporation rate, the seasonal water discharge from the Al-Sannaf marsh, and the average water discharge from Iran were obtained from IMWR-CRIM (2006).

2.3.2 Water sampling strategy

The monitoring stations for water sampling were made based on scientific objectives and accessibility one in each Iraqi inlet rivers (Al-Mshereh, Al-Zubair, Um Al-Tooss, and Al-Husachi rivers) and outlet (Table 1, Figure 9). Sampling was carried on a monthly basis from May 2006 to March 2007.

Water samples for measurement of P and N species were collected from approximately 50 cm below the surface with a Van Dorn water sampler. Triplicate water samples (~500 ml) were immediately filtered through a pre-washed (Stainton *et al.*, 1977) and pre-weighted GF/F filter (0.7 µm, 47 mm). The filtrates were transferred into translucent polyethylene screw-cap bottles. Filtrates used to determine NO_2^-, NO_3^-, and PO_4^- were preserved with 5 drops of chloroform (Stainton *et al.*, 1977). Another 50 ml of filtrate was transferred into screw-capped test tubes and digested with 1.5 ml of 3% potassium persulfate for the determination of TDP concentrations (Menzel & Corwin, 1965). To determine TDN concentrations, 30 ml of the filtrate was transferred into a screw-capped test tube and digested with 4 ml of oxidation reagent

(Valderrama, 1981). Filters with particulate matter were transferred immediately to disposable Petri-dishes and stored at 4 °C (Stainton *et al.*, 1977; Wetzel & Likens, 1991) in order to determine PP and PN.

Table 1: The coordinates of the water measurements and sampling stations in the four Iraqi inlet and two outlet rivers of Hour Al-Hawizeh

		Latitude and Longitude					
Station	**Station symbol**	**North**			**East**		
Al-Mshereh	**1**	31°	40´	47″	47°	37´	24″
Al-Zubair	**2**	31°	38´	56″	47°	34´	39″
Um Al-Toos	**3**	31°	37´	0″	47°	33´	8″
Al-Husachi[1]	**4**	31°	34´	3″	47°	30´	2″
	5	31°	34´	6″	47°	30´	4″
Al-Kassara	**6**	31°	20´	57″	47°	27´	16″
Al-Suwayb	**7**	30°	58´	7″	47°	29´	27″

[1] The two sampling stations of Al-Husachi river are Al-Adil (4) and Old Al-Adil (5)

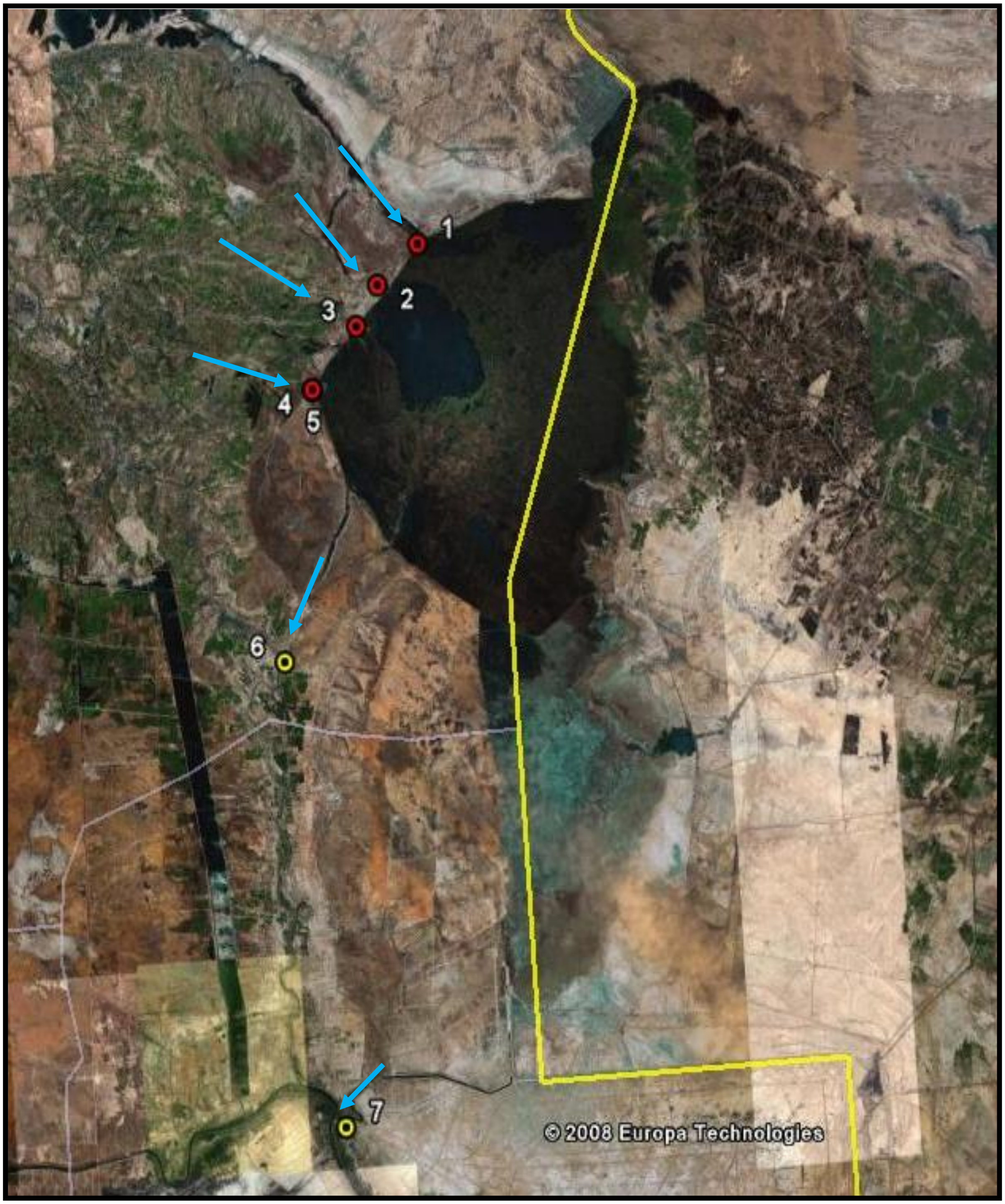


Figure 9: The water sampling stations. Photo adapted from Google earth, January 2008. The latitude and longitude coordinates are listed in table 1.

2.3.3 Laboratory analysis

2.3.3.1 Total phosphorus (TP)

The ascorbic acid method described by Stainton *et al.* (1977) was used to determine PO_4^- concentrations in the water. However, due to the low concentration of PO_4^- in the water, 50 ml water samples were used in order to increase the accuracy of the analysis. PO_4^- samples were measured using a 1 cm quartz cell in a Shimadzu spectrophotometer at 885 nm.

The concentrations of DP in the water samples and PP on the filters were determined by converting the organic phosphorus into orthophosphate in the presence of potassium persulphate (Stainton *et al.* 1977). The samples were placed in a hot water bath for approximately 1 hour to improve the digestion process. The digested samples then were measured following the ascorbic acid method. However, the PP samples were measured using a 5 cm quartz cell in a Biokhrom (Ultrospec 3100 pro) spectrophotometer at 885 nm. The concentrations of DOP were calculated by subscripting the concentrations of PO_4^- from the concentrations of DP. The sum of DP and PP is the TP concentration.

2.3.3.2 Total nitrogen (TN)

The pink azo dye method described by Staninton *et al.* (1977) was used to determined NO_2^- concentrations in the water. Samples used to determine NO_3^- concentration were reduced to nitrite by passing them through a cadmium-copper column and measured as described above. The DN concentrations in the water were measured by the method described by Valderrama (1981). The samples were digested first to convert the different N forms into NO_3^- in the presence of the oxidation reagent. The samples were also placed in a hot water bath for an approximately 1 hour in order to increase the activity of the digestion process. Then NO_3^- was reduced to NO_2^- and NO_2^- was measured using a 1 cm quartz cell in a Shimadzu spectrophotometer at 543 nm. The PN samples were packed in 7 x 5 mm nickel capsules. The elemental analysis developed by Zimmermann & Keefe (1997) was used to determine the PON concentration in the water. The concentration of DON was calculated approximately by subtracting the concentrations of NO_2^- and NO_3^- from the concentrations of DN as previous studies found very low concentrations of NH_4^+ in the Iraqi marshes. The TN concentrations then were calculated by the summation of DN and PON in the water samples.

2.3.4 Method of estimating TP and TN budgets of Hour Al-Hawizeh

The differences between the annual TP and TN load and export were used to calculate the TP and TN budgets of Hour Al-Hawizeh (Dolan *et al*., 1981; Mukhopadhyay & Smith, 2000). The following equation was developed from Mukhopadhyay & Smith (2000) shows how I calculated the TP and TN budgets (**TP/TN*B***):

TP/TN*B* (tons/year) = annual L_{in} (ton) – annual Y_{out} (ton)

L_{in} is the annual load of TP and TN into Hour Al-Hawizeh, which calculated by taking the average load of TP and TN from the period of May 2006 to March 2007 and multiplying it by 12. Y_{out} is the annual export of TP and TN from Hour Al-Hawizeh, which calculates as same as L_{in}.

1. TP and TN loading by Iraqi inlets:

The TP and TN concentration were measured in the four Iraqi rivers, the Al-Mshereh, Al-Zubair, Um Al-Toos, and Al-Husachi rivers were multiplied by their monthly water discharge. The TP and TN load by the Al-Sannaf inlet were calculated by taking the average concentration of TP and N in the Al-Mshereh River and multiplying it by the water discharge of the Al-Sannaf inlet because they tend to have a similar water quality.

2. TP and TN loading by Al-Karkheh tributaries:

The DIP and DIN load by the Iranian inlets were obtained from the Iraqi Ministry of Water Resources, while the average concentrations of DOP, DON, PP, and PN in the four Iraqi rivers were used to complete the TP and TN load.

3. TP and TN loading by direct precipitation

The contribution of TP and TN from direct precipitation was calculated based on the annual TP and TN load calculated by Serruya (1975).

4. The TP and TN export from Hour Al-Hawizeh

The monthly concentrations of TP and TN were calculated in the Al-Suwayb and Al-Kassara outlets were multiplied by the monthly water discharge of each outlet.

Then the annual TP and TN load into and export from Hour Al-Hawizeh were used to calculate the annual budget of TP and TN.

2.3.5 Method of estimating P and N fraction budgets of Hour Al-Hawizeh

The same method used to estimate the TP and TN budget were used to estimate their fractions. In this study, DIP, DIN, DOP, DON, PP, and PN in the four Iraqi rivers were measured. However, the same difficulties that affect the estimation of TP and TN load by the Iranian inlets, Al-Sannaf inlet, and rainfall affect the estimation of their fractions.

The annual load of DIP and DIN by the Iranian tributaries was taken from the Iraqi Ministry of Water Resources, while the annual average concentrations of DOP, DON, PP, and PN by the four Iraqi rivers were used to calculate an approximate load by the Iranian tributaries. The approximate load of TP and TN fractions by the Al-Sannaf marsh was calculated by taking the average concentration of DIP, DIN, DOP, DON, PP, and PN in the Al-Mshereh River. Due to the very low amount of rain during the wet season, the TP and TN fractions in the rainfall were excluded from budget.

2.4 Results

2.4.1 Water budget

The total annual water discharge into Hour Al-Hawizeh was approximately 436.3 x 10^7 m^3. The water discharge from Iraq represents approximately 74.32% of the total discharge, while the percentage of water discharge from Iran and rainfall were approximately 25.66% and 0.01%, respectively.

The annual water discharge from the Iraqi rivers into Hour Al-Hawizeh was approximately 196.3 x 10^7 m^3 (Table 2). It was high during late spring (May 2006) and winter (November 2006 to February 2007) with a maximum value of 23×10^7 m^3 in December (Table 2). During the summer and fall water discharge was reduced, reaching lowest value of 7×10^7 m^3 in October 2006 (Figure 10). According to the IMWR-CRIM (2006), the monthly average water discharge from the Al-Sannaf marsh from January to July 2006 was 128.0 x 10^7 m^3. The highest water discharge (54.4 x 10^7 m^3) occurred in January 2006, while no water discharged into Hour Al-Hawizeh during the summer (Table 2). The average annual rainfall input from 1982 to 2005 was 3.3 x 10^5 m^3 (Table 2). The average annual water discharge for 2007 by the three tributaries of the Al-Karkha River into Hour Al-Hawizeh was 112 x 10^7 m^3.

The total annual water discharge from Hour Al-Hawizeh by the Al-Kassara and Al-Suwayb rivers was approximately 308.9 x 10^7 m^3. Their water discharge was high in winter and low in late summer. The highest water discharge was 38.6×10^7 m^3 in February 2007, while the lowest discharge was 5.9 $\times10^7$ m^3 in October 2006 (Table 2). The Al-Suwayb River had the highest water discharge during the study period with a proportion of approximately 86% (Table 2). On the other hand, the average annual water loss by evaporation was 42.2 x 10^7 m^3 (Table 2). This represents approximately 12% of the total annual water export from Hour Al-Hawizeh.

Table 2: The available monthly data of water discharge (1×10^7 m^3) of the inlets and outlets of Hour Al-Hawizeh.

	Mshereh	Zubair	Um Al-Toos	Husachi	[1]Iranian inlets	[2]Sannaf inlet	[3]Precipitation	[4]Evaporation	Kassara	Suwayb
May-06	3.2	2.6	7.3	4.3	-	2.5	0.000252	4.9	12.2	1.8
Jun-06	2.8	3.1	5.8	4.7	-	1.9	0.000018	6.6	2.0	29.2
Jul-06	2.9	3.1	4.2	3.9	-	0.8	0.000000	6.9	2.0	28.2
Aug-06	2.0	2.1	4.5	3.1	-	0.0	0.000000	6.5	1.8	13.2
Sep-06	1.9	3.0	4.4	3.2	-	0.0	0.000234	4.7	1.5	5.7
Oct-06	1.2	1.6	2.6	2.1	-	0.0	0.001152	3.2	1.0	4.9
Nov-06	3.6	3.5	7.5	3.5	-	0.0	0.004068	1.6	1.7	30.3
Dec-06	4.6	4.0	8.7	5.7	-	0.0	0.006372	0.9	2.7	32.7
Jan-07	3.7	3.8	8.2	5.2	-	54.4	0.006282	0.8	2.6	32.3
Feb-07	4.5	2.6	8.4	5.5	-	39.4	0.003672	1.2	2.5	36.1
Mar-07	4.2	1.6	5.1	3.9	-	24.6	0.007290	2.1	8.6	29.8
Apr-07	2.9		[5]16.2		-	4.5	0.003312	3.0	-	-
Annual	**37.3**	**36.4**	**72.1**	**50.5**	**112.0**	**128.0**	**0.032652**	**42.2**	**42.4**	**266.5**

[1] The average annual water discharge of the Iranian inlets provided by personal contact in the Center of Restoration of Iraqi Marshlands
[2] Data provided from IMWR-CRIM, 2006.
[3] The average monthly precipitation from 1982 until 2005. Data provided from IMWR-CRIM, 2006.
[4] The average monthly evaporation in 2005. Data provided from IMWR-CRIM, 2006.
[5] The water discharge was measured in the Al-Kahla River before it is divided in to tributaries. Data provided from IMWR-CRIM, 2006.

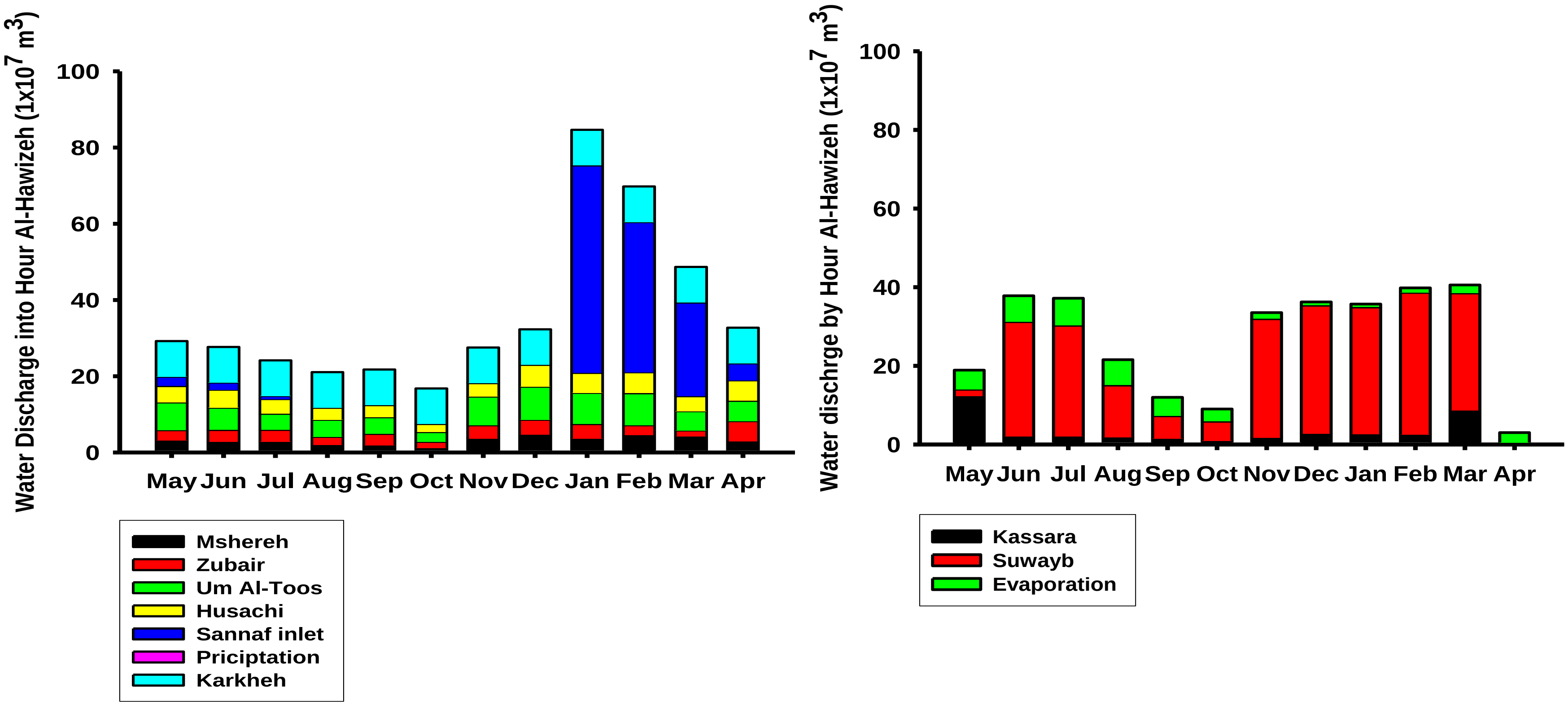


Figure 10: Total annual water load into Hour Al-Hawizeh and export from May 2006 to April 2007. Water discharge from the Iran, Al-Sannaf marsh, precipitation, and evaporation were provided from IMWR-CRIM, 2006, while water discharge by the Al-Mshereh, Al-Zubair, Um Al-Toos, Al-Husachi rivers, and water discharge exports by the Al-Kassara and Al-Suwayb rivers were provided from the Iraqi Ministry of Water Resources.

2.4.2 Phosphorus and nitrogen budgets

2.4.2.1 P and N load into Hour Al-Hawizeh

In this study, the annual TP and TN load into Hour Al-Hawizeh by the Iraqi inlets, Iran, and rainfall were approximately 341.4 tons and 913.8 tons/year respectively (Figure 11). The annual TP and TN load by the four Iraqi rivers were 223 tons and 704.8 tons, respectively. The estimated annual load of TP by the Al-Sannaf marsh, Al-Karkheh River, and rainfall were approximately 110.4 tons, 8.0 tons, and 0.1 ton, respectively. The estimated annual TN load by the Al-Sannaf marsh, Al-Karkheh River, and precipitation were approximately 181.7 tons, 27.0 tons, and 0.3 ton, respectively.

Practically 98% of the TP and 97% TN load were imported from Iraq into Hour Al-Hawizeh. The seasonal load of TP and TN from the Al-Sannaf marsh was nearly 32% and 21% of the annual load, respectively. Al-Karkheh River imports more or less than 3% TP and 2% of TN of the total annual load. The percentages of TP and TN load by rainfall were 0.02% and 0.03%, respectively.

TP and TN load into Hour Al-Hawizeh were high in winter and low in summer (Figure 11). However, TN load was also high in spring. The maximum load of TP was 112.5 tons in January 2007, while the maximum TN load was 165.8 tons in March 2007 (Figure 11). The minimum load of TP and TN were 7.4 tons and 26.9 tons in October 2006, respectively (Figure 11).

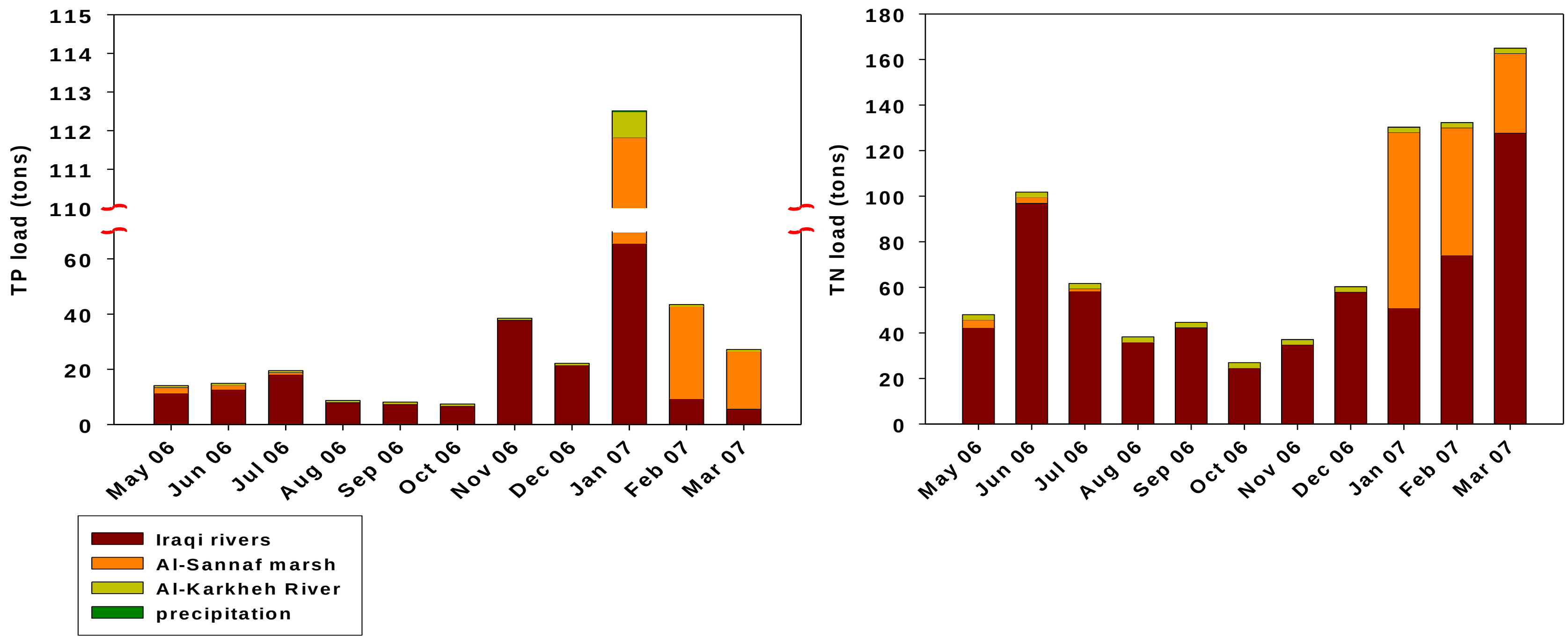


Figure 11: Monthly variation of TP and TN load into Hour Al-Hawizeh from May 2006 to March 2007.

The annual TP and TN load by the Iraqi Rivers (Al-Mshereh, Al-Zubair, Um Al-Toos, and Al-Husachi) into Hour Al-Hawizeh were 223.0 tons and 704.8 tons, respectively (Figures 12 & 13). TP load, by the Iraqi Rivers, was high during November 2006, December 2006, and January 2007(Figure 12), while TN loading was high during February and March 2007(Figure 13). In summer, TP loading was low, especially from August 2006 to October 2006 (Figure 12), while TN loading was low during October and November 2006 (Figure 13).

In this study, 58% of the annual TP loading by the Iraqi rivers was DOP, which was about 130 tons/year (Table 4), while PO_4^- and PP loads were 62 tons/year and 31/year tons, respectively (Table 4). On the other hand, 63% of the TN load by the Iraqi rivers was PN, which was about 442.4 tons/year (Table 4). The DIN and DON load were 89.9 tons/year and 172.4 tons/year, respectively (Table 4). Among the four Iraqi rivers, the Um Al-Toos River carries approximately 43.7% of the TP and 39% of the TN loading into Hour Al-Hawizeh. The Al-Husachi River carries approximately 40% of TN into Hour Al-Hawizeh.

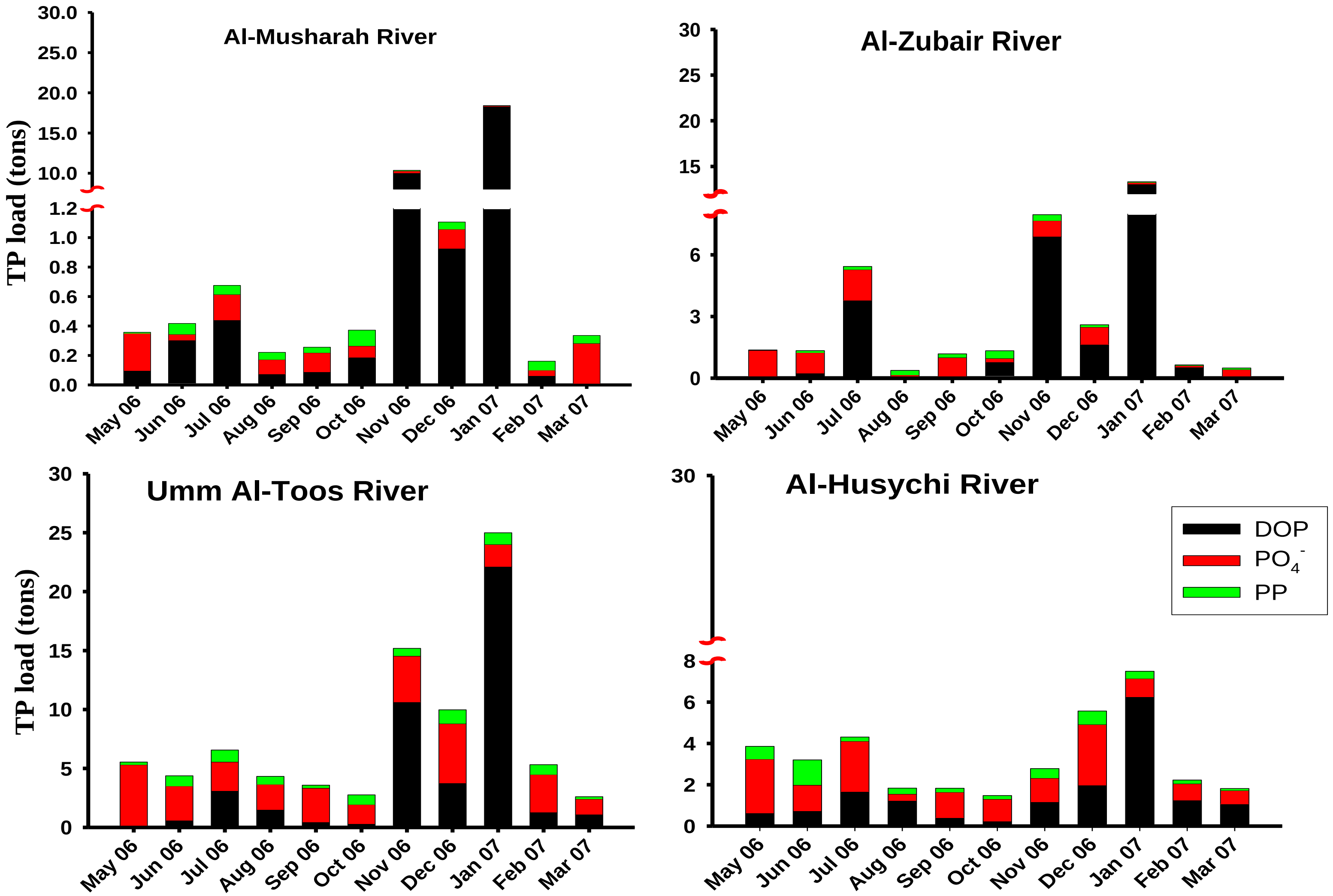


Figure 12: Monthly variation of phosphorus fractions load into Hour Al-Hawizeh by the four Iraqi rivers from May 2006 to March 2007.

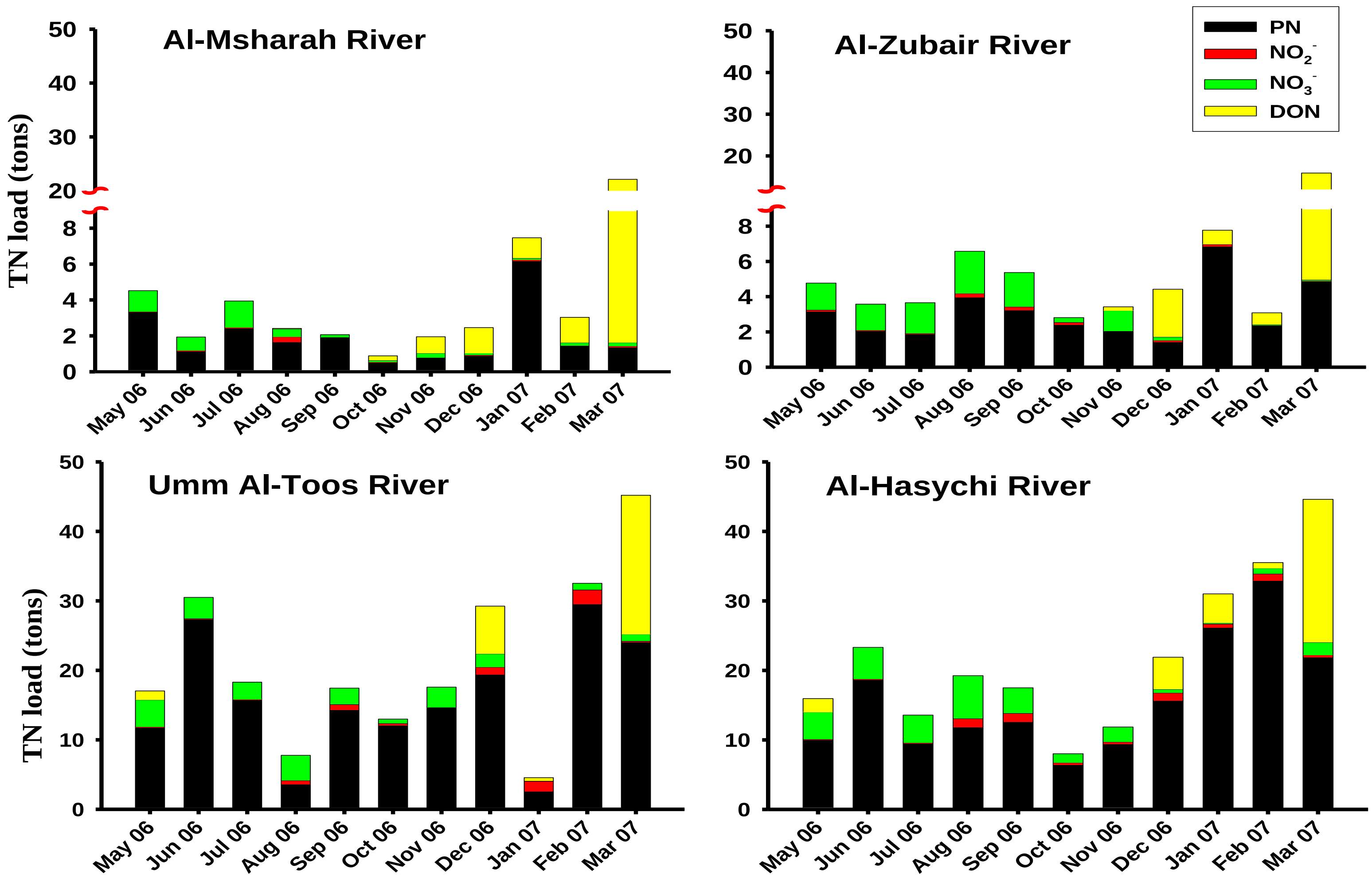


Figure 13: Monthly variation of nitrogen fractions load into Hour Al-Hawizeh by the four Iraqi rivers from May 2006 to March 2007.

Table 3: The average and range of monthly orthophosphate (PO_4^-), nitrite (NO_2^-), nitrate (NO_3^-), dissolved organic phosphorus (DOP), dissolved organic nitrogen (DON), particulate phosphorus (PP), particulate nitrogen (PN), total phosphorus (TP), and total nitrogen (TN) load (tons) into Hour Al-Hawizeh by the four Iraqi rivers from May 2006 to March 2007.

	Al-Mshereh		Al-Zubair		Um Al-Toos		Al-Husachi	
	Average	Range	Average	Range	Average	Range	Average	Range
PO_4^-	0.1	<0.1-0.3	0.7	0.1-1.5	3.0	1.3-5.2	1.4	0.3-2.9
NO_2^-	0.1	<0.1-0.3	0.1	<0.1-0.2	0.6	0.1-2.1	0.6	0.1-1.3
NO_3^-	0.4	0.1-1.5	1.0	<0.1-2.4	2.1	<0.1-3.9	2.6	0.2-6.2
DOP	2.8	<0.1-18.3	2.5	<0.1-13.0	4.1	0.1-22.1	1.5	0.2-6.3
DON*	3.7	<0.1-20.5	2.1	<0.1-11.0	4.1	<0.1-20.0	4.5	<0.1-20.6
PP	0.1	<0.1-0.2	0.2	<0.1-0.5	1.1	0.3-1.9	1.2	0.3-3.9
PN	2.0	0.5-6.2	3.1	1.4-6.8	15.9	2.5-29.5	15.9	6.4-32.9
TP	3.0	0.2-18.4	3.4	0.5-13.4	8.1	2.7-25.6	4.1	2.0-8.3
TN	6.2	0.9-22.1	6.3	2.8-15.9	22.6	4.6-45.2	23.6	8.0-44.6

*= The missing data of TDN in June and July 2006 were estimated approximately by taking the sum of the month before and after and divided by two

Table 4: Monthly and annual load (tons) of orthophosphate (PO_4^-), nitrite (NO_2^-), nitrate (NO_3^-), dissolved organic phosphorus (DOP), dissolved organic nitrogen (DON), particulate phosphorus (PP), particulate nitrogen (PN), total phosphorus (TP), and total nitrogen (TN) into Hour Al-Hawizeh by the four Iraqi rivers from May 2006 to March 2007.

	May-06	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06	Jan-07	Feb-07	Mar-07	Annual
PO_4^-	9.3	5.2	6.6	2.7	5.2	3.0	6.1	8.9	3.1	4.1	2.6	**62.0**
DIN	10.9	10.2	10.0	14.9	10.3	3.0	6.8	5.1	2.5	5.0	3.7	**90.0**
DOP	0.9	1.8	9.0	2.9	1.0	1.5	28.7	8.3	59.7	3.1	2.2	**129.9**
DON	3.2	0.0	0.0	0.0	0.0	0.3	1.1	15.6	6.5	2.9	72.0	**110.9**
PP	1.1	5.6	2.6	2.5	1.3	2.3	3.0	4.2	2.9	2.1	0.8	**31.1**
PN	28.2	49.1	29.5	21.0	32.0	21.4	26.9	37.3	41.7	66.2	52.1	**442.4**
TP	11.3	12.6	18.2	8.0	7.4	6.8	37.8	21.5	65.7	9.4	5.7	**223.3**
TN	42.3	96.9	58.3	36.0	42.4	24.7	34.8	58.0	50.8	74.1	127.8	**704.8**

2.4.2.2 Phosphorus and nitrogen export from Hour Al-Hawizeh

The annual export of TP and TN from Hour Al-Hawizeh by the Al-Kassara and Al-Suwayb Rivers were approximately 213.4 tons and 1151.0 tons, respectively.

TP and TN export was high from June and July 2006 and low from August 2006 to October 2006 (Figure 14). The TN export was relatively high during the study period except in October when it became low, less than 10.0 tons (Figure 14). The average TP export by the Al-Kassara and Al-Suwayb Rivers were 1.0 tons/month, 16.9 tons/month, respectively (Table 5), while the average TN export by the Al-Kassara and Al-Suwayb Rivers were 7.4 tons/month, and 88.5 tons/month, respectively (Table 5). The Al-Suwayb River exports 94.2% of TP and 92.2% of TN comparing to the Al-Kassara River.

This study indicates that 87.6% of the annual TP export was DOP, which was about 188.3 tons (Table 7). The annual PO_4^- and PP export were 13.8 tons and 11.3 tons, respectively (Table 7). On the other hand, 60.8% of the annual TN export was PN, which was about 699.4 tons. NO_2^-, NO_3^-, and DON load were 7.6, 33.5, and 410.5 tons, respectively (Table 7).

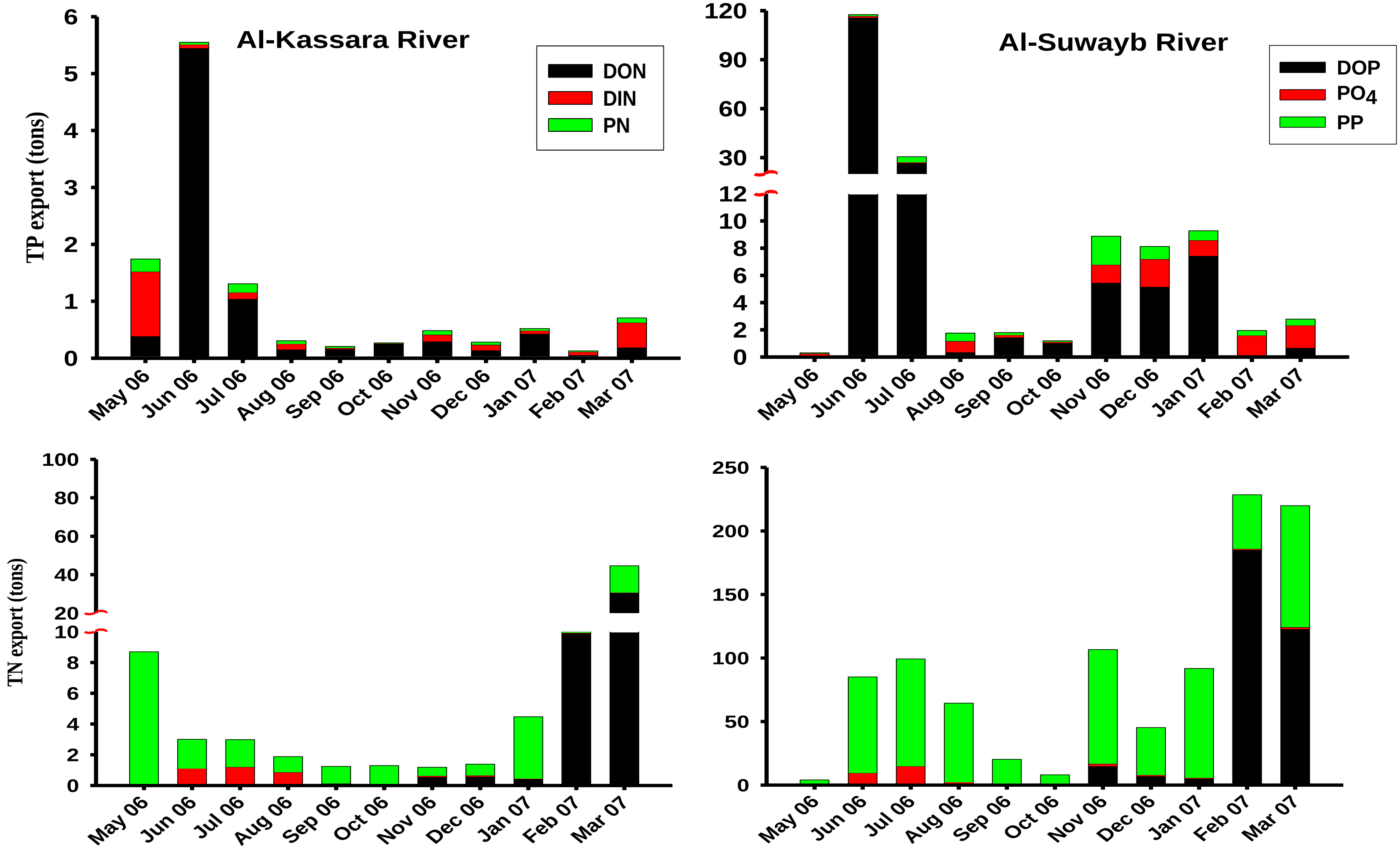


Figure 14: Monthly variation of phosphorus and nitrogen fractions export from Hour Al-Hawizeh from May 2006 to March 2007.

Table 5: The average and range of monthly orthophosphate (PO_4^-), nitrite (NO_2^-), nitrate (NO_3^-), dissolved organic phosphorus (DOP), dissolved organic nitrogen (DON), particulate phosphorus (PP), particulate nitrogen (PN), total phosphorus (TP), and total nitrogen (TN) export (tons) by the Al-Suwayb and Al-Kassara rivers from May 2006 to March 2007.

	Al-Kassara		Al-Suwayb	
	Average	**Range**	**Average**	**Range**
PO_4^-	0.2	<0.1-1.1	1.0	0.1-2.0
NO_2^-	0.6	<0.1-3.3	0.0	<0.1-0.1
NO_3^-	2.5	0.1-11.6	0.7	<0.1-1.1
DOP	0.8	0.1-5.4	14.9	<0.1-115.8
DON	33.5	<0.1-185.0	5.5	<0.1-30.4
PP	0.2	<0.1-0.2	0.9	0.1-3.3
PN	55.0	3.9-95.8	6.6	0.5-13.9
TP	1.0	0.1-5.6	16.9	0.3-117.8
TN	88.5	4.0-228.5	11.9	1.2-44.6

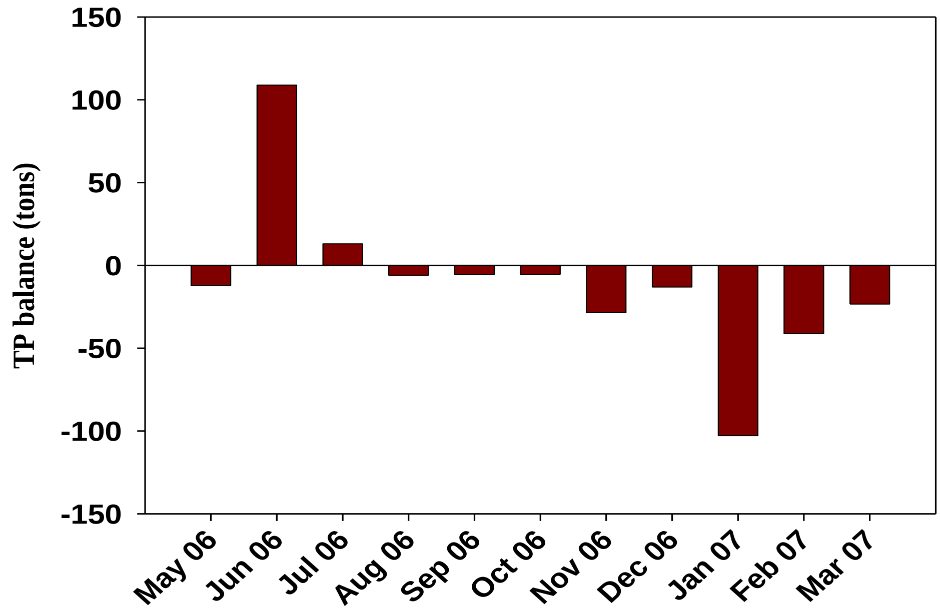
Table 6: Monthly and annual export (tons) of orthophosphate (PO_4^-), nitrite (NO_2^-), nitrate (NO_3^-), dissolved organic phosphorus (DOP), dissolved organic nitrogen (DON), particulate phosphorus (PP), particulate nitrogen (PN), total phosphorus (TP), and total nitrogen (TN) by the Al-Suwayb and Al-Kassara rivers from May 2006 to March 2007.

	May-06	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06	Jan-07	Feb-07	Mar-07	Annual
PO_4^-	1.4	1.0	0.6	0.9	0.2	0.1	1.4	2.1	1.2	1.6	2.1	**13.8**
DIN	0.2	10.7	16.1	3.3	0.5	0.4	1.8	1.3	0.8	1.0	1.7	**41.1**
DOP	0.4	121.2	27.2	0.5	1.6	1.3	5.7	5.3	7.9	0.1	0.9	**188.8**
DON	0.0	0.0	0.0	0.0	0.0	0.0	15.5	7.4	5.4	194.9	153.1	**410.5**
PP	0.3	0.9	3.5	0.6	0.2	0.1	2.2	1.0	0.7	0.4	0.5	**11.3**
PN	12.6	77.5	86.2	63.1	20.9	8.9	90.5	38.0	90.0	43.7	109.7	**699.4**
TP	2.0	123.1	31.8	2.1	2.0	1.5	9.4	8.4	9.8	2.1	3.5	**213.4**
TN	12.7	88.1	102.3	66.4	21.5	9.3	107.8	46.6	96.2	239.6	264.5	**1151.0**

2.4.2.3 Phosphorus and nitrogen balance

The annual balance of TP shows that 128.0 tons of TP remained within Hour Al-Hawizeh, while 237.4 tons of TN was released from the Hour (Figure 15). The maximum retention of TP was 102.8 tons in January 2007, while the minimum retention of TP was 5.3 tons in October 2006 (Table 7). The maximum release of TP was 108.8 tons in June 2006 and the minimum release was 13.0 tons in July 2006 (Table 7).

The estimated budget indicates that the high retention amount of TN occurred in September 2006 and January 2007, 23.1 tons and 34.1 tons, respectively (Table 7). The lower retention of TN occurred in June and December 2006 were 13.7 tons and 13.6 tons, respectively (Table 7). The highest amount of TN released from Hour Al-Hawizeh was 107.3 tons in February 2007, while the minimum release of TN was 15.0 tons in May 2006 (Table 7).



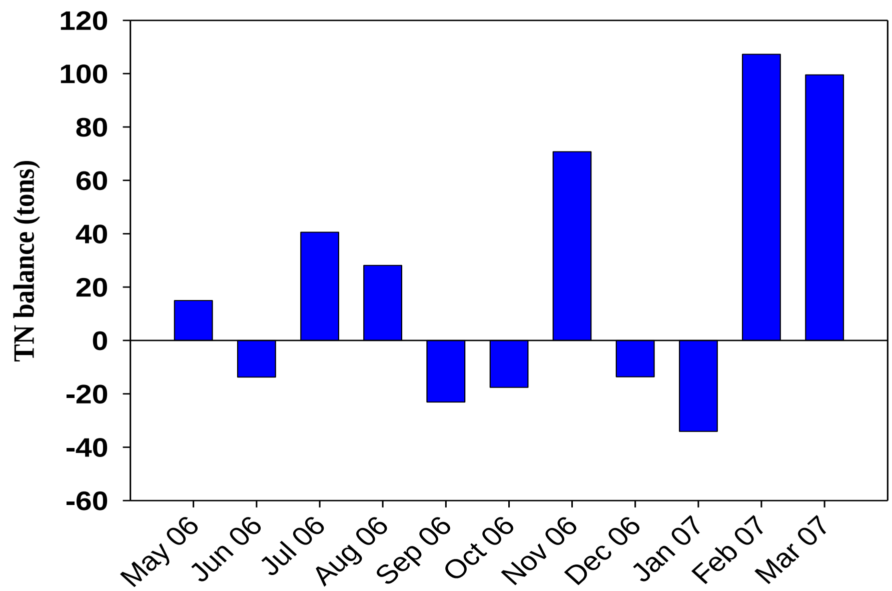


Figure 15: Monthly balance of TP and TN of Hour Al-Hawizeh from May 2006 to March 2007.

Table 7: Monthly and annual balance of TP and TN (tons) in Hour Al-Hawizeh from May 2006 to March 2007.

	May-06	Jun-06	Jul-06	Aug-06	Sep-06	Oct-06	Nov-06	Dec-06	Jan-07	Feb-07	Mar-07	Annual
TP in	14.1	14.3	18.9	8.0	7.4	6.8	37.8	21.5	112.6	43.3	26.8	**341.4**
TP out	2.0	123.1	31.8	2.1	2.0	1.5	9.4	8.4	9.8	2.1	3.5	**213.4**
TP net	-12.1	108.8	13.0	-6.0	-5.5	-5.3	-28.5	-13.1	-102.8	-41.3	-23.3	**-128.0**
TN in	48.0	101.9	61.7	38.2	44.6	26.9	37.1	60.3	130.3	132.3	164.9	**931.5**
TN out	12.7	88.1	102.3	66.4	21.5	9.3	107.8	46.6	96.2	239.6	264.5	**1151.0**
TN net	15.0	-13.7	40.5	28.1	-23.1	-17.6	70.8	-13.6	-34.1	107.3	99.6	**237.4**

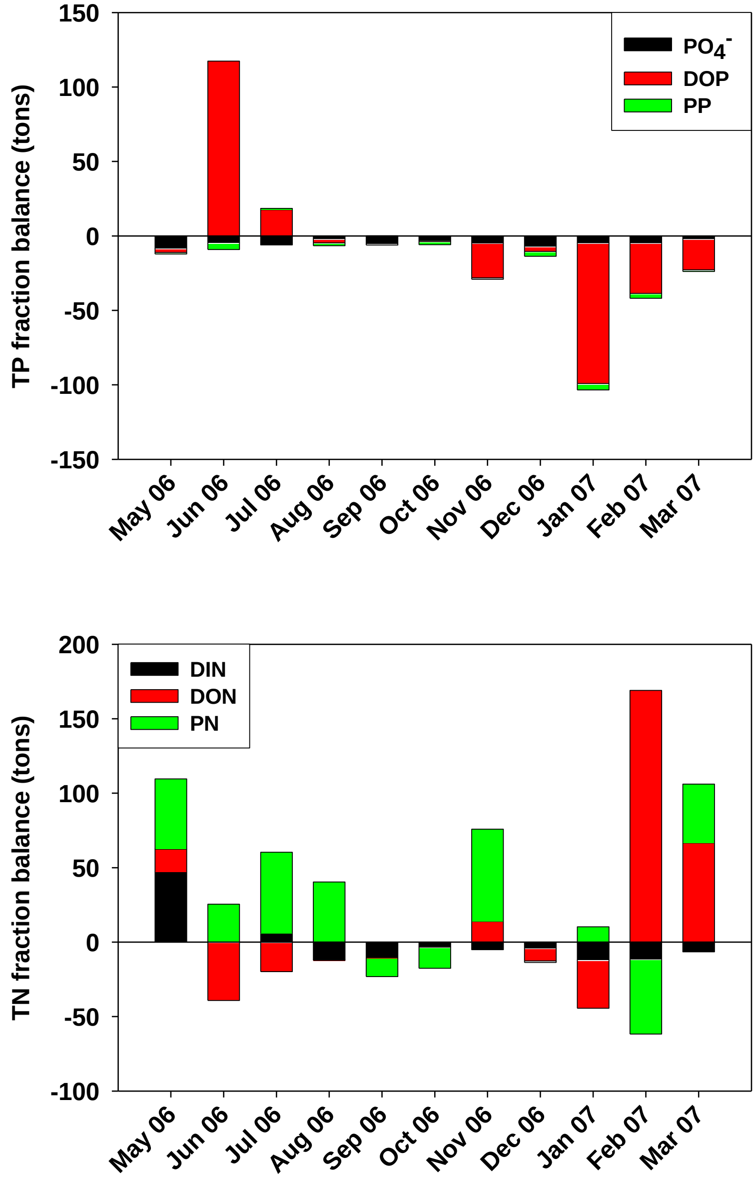


Figure 16: Monthly balance of P and N fractions (tons) of Hour Al-Hawizeh from May 2006 to March 2007.

2.5 Discussion: Phosphorus and nitrogen budget

2.5.1 Phosphorus and nitrogen load into Hour Al-Hawizeh

During the study period, TP and TN load into Hour Al-Hewaizah showed seasonal variation, which was high in winter and low in summer (Figure 11). This variation was strongly influenced by the water discharge as has been observed elsewhere (Cole & Fisher, 1979; Van Geldermalsen, 1985; Yanagi, 1999; Reinhardt *et al.*, 2005). Such a positive relationship between the water discharge and TP and TN load was also found in different studies especially ones that focus on river-fed wetlands (Hussain, 1992; Krah *et al.*, 2006; Panigrahi *et al.*, 2007). More than 99% of TP and TN that enter Hour Al-Hawizeh were transport through surface water and less than 1% of the load is from rainfall. This indicates that rivers are the main sources of TP and TN load into Hour Al-Hawizeh rather than rainfall (Figure 10). In this case, future studies can focus on surface water more that precipitation as main sources of P and N into the marshes.

As the water discharge associated with the amount of TP and TN enters Hour Al-Hawizah. It is worth mentioning that the seasonal fluctuation of water discharge of the Iraqi rivers is related to both natural and artificial conditions, which has a significant impact on increase or decrease the TP and TN loading. For example, snowmelt in spring is one of the natural sources of water that increase the water discharge and thus increase the nutrients load (Al-Saadi *et al.*, 1981; IMWR-CRIM, 2006). On the other hand, dams are the main artificial factors that reduce water discharge and thus decrease the amount of nutrient load (IMWR-CRIM, 2006).

In this study, TN load into Hour Al-Hawizeh was approximately 3 times higher than TP load. Such a concept was also found in different studies. For example, in the Okavango Delta, the TN loading was twelve times higher than TP load (Krah *et al.*, 2006). This was mainly because there were no other sources to supplement the loss of P in the Delta (Krah *et al.*, 2006). In case of the Hakata Bay, Japan, TN loading was twice the amount of TP loading (Yanagi, 1999). On the other hand, in Lake Agmon, Israel, TP:TN load ratio was 1:119.3 (Gophen, 2000). This was mainly due to the high peat erosion entering the Lake, which is mainly N (Gophen, 2000).

During the study period, the Iraqi rivers carried approximately 76% of TP and 70% of TN loading into Hour Al-Hawizeh. The Um Al-Toos River carried approximately 44% of TP and 40% of TN (Figure 11). This was mainly because it has the highest water discharge (IMWR-CRIM, 2006), and heavily loaded with untreated domestic waste and detergents from the villages located along the riverbanks (IMWR-CRIM, 2006). On the other hand, the Al-Husachi River carried the highest percentage of TN into Hour Al-Hawizeh among the three other rivers, which was approximately 41% (Figure 12). This was mainly due to the heavy fertilizer added from the surrounding agricultural farms (IMWR-CRIM, 2006). The investigation indicates most of the fertilizer used in farms close to the Al-Husachi River is organic, such as animal manure. The influence of these agriculture farms became noticeable, especially during the preparation for the planting (Figure 12). The TP and TN load by the other Iraqi inlets were low, mainly because of their low discharge (IMWR-CRIM, 2006). In case of the Al-Mshereh and Al-Zubair Rivers, the irrigation canals constructed upstream strongly decrease their water velocity (IMWR-CRIM, 2006), and thus enhance plant growth, especially *Phragmites* and *Ceratophyllum*. Plants consume P and N, and reduce their concentration in the water, then eventually decrease their load. The estimated TP and TN load into Hour Al-Hawizeh by the Al-Sannaf marsh was reasonable (Figure 11). However, the extream fluctuation of water flows from the Al-Sannaf marsh into Hour Al-Hawizah led to affect the TP and TN load seasonally. In winter and spring, TP and TN load by the Al-Sannaf marsh was high because the huge amount of water enters Hour al-Hawizah, especially when the water level in the Al-Sannaf marsh became over its capacity (IMWR-CRIM, 2006). While in summer, there is nutrient load from the Al-Sannaf marsh into Hour Al-Hawizah because there is no water discharge. In addition, the estimated amount of TP and TN entering Hour Al-Hawizeh by rainfall is also low (Figure 11). This was mainly because the area did not receive much rainfall in winter during the study period. The recent Iraqi studies indicate that the precipitation rate in Iraq has decreased ten times in the last 20 years (Maulood & Boney, 1980; Al-Saadi *et al*., 1981). In contrast, different studies found that rain could be an additional way to increase the TP and TN in the aquatic systems by precipitating dust particles (Krah *et al*., 2006).

2.5.2 Phosphorus and nitrogen fractions load into Hour Al-Hawizeh by the Iraqi rivers

In this study, about 58 % of the TP and 69% of the TN enters Hour Al-Hawizeh by the Al-Mshereh, Al-Zubair, Um Al-Toos, and Al-Husachi Rivers was DOP and PN, respectively. About 38% of DOP was carried by the Um Al-Toos River. The Um Al-Toos River and the Al-Husachi River each carry approximately 40% of the TN load. Dissolved detergents and untreated domestic waste, which are added from the villages located upstream on the Um Al-Toos River, are likely the main reason behind the high amount of P and N component to the other inlets (Al-Mousawi & Hussain, 1992; Ghliem, 2001; IMWR-CRIM, 2006). On the other hand, soil particulates, organic fertilizer, and plant litter are the main sources of extra P and N in the Al-Husachi River as has been found in other studies (Benson-Evans *et al*., 1999; Ghliem, 2001; IMWR-CRIM, 2006; Panigrahi *et al.*, 2007). Field investigation indicates that most farmers usually flush their farms with water before they grow crops, especially the rice fields. Then the flush of water flows directly to the drainage channels then into the Al-Husachi River. The soil particles have high concentration of N that P because of the use of manure and plants debris as fertilizer. DOP was the main fraction of TP load in different studies, such as Lake Agmon (Hambright, 1998; Gophen 2000) and the Sonnhof wetland (Reinhardt *et al.*, 2005).

2.5.3 Phosphorus and nitrogen export from Hour Al-Hawizeh

The TP and TN export by the two outlets are mediated by the biological activities within the marshes (Gophen 2000; Al-Mousawi & Hussain, 1992; Okbah, 2005; Panigrahi *et al*., 2007) and hydrological events in the outlets (Cole & Fisher, 1979; Van Geldermalsen, 1985; Yanagi, 1999; Reinhardt *et al.*, 2005). Plant production is the main biological activity within an aquatic system that can have a main impact on nutrient export (Al-Mousawi & Hussain, 1992; Alwan, 1992). On the other hand, particulate sedimentation and decomposition could be the main physio-chemical activities that affect the amount of nutrient export (Yanagi, 1999; Krah *et al.*, 2006). Water discharge could also affect the amount of nutrients export as it found in different studies (Cole & Fisher, 1979; Van Geldermalsen, 1985; Yanagi, 1999; Reinhardt *et al.*, 2005).

During the study period, the monthly export of TP and TN by both the Al-Suwayb and Al-Kassara rivers was high in spring and winter, and low in late summer. This seasonal fluctuation, especially in the Al-Suwayb River, was mainly due to the water discharge and slightly due to the biological and chemical activities within Hour Al-Hawizeh. The high amount of TP and TN export from Hour Al-Hawizeh during June and July 2006 were mainly due to the extensive production of phytoplankton within the marshes (Al-Mousawi & Hussain, 1992; Alwan, 1992). The loss of water in summer via evaporation is also concentrate TP and TN concentration within the system (Van Geldermalsen, 1985; Yanagi, 1999; Reinhardt *et al.*, 2005). Although in summer the TP and TN concentration in Hour Al-Hawizeh might be increase due to the decrease in water level caused by the high evaporation, the water export was also low, especially in the Al-Suwayb River. The decomposition of litters and organic matter in winter could be the main reason for the increase in TP and TN export in the outlets (Figure 14).

The contribution of different P and N fractions export from Hour Al-Hawizeh were mainly influenced by plant production (Gophen, 2000; Al-Mousawi & Hussain, 1992; Okbah, 2005; Panigrahi *et al*., 2007), sedimentation, and re-suspension (Birch & Spyridakis, 1981; Gophen, 2000; Okbah, 2005) within the marshes. Generally, about 88 % of the TP and 61% of TN exports by the Al-Suwayb and Al-Kassara Rivers were DOP and PN, respectively. The Al-Suwayb River exports most of TP (82%) and TN (62%) from Hour Al-Hawizeh. This was mainly because of its high water discharge comparing to the Al-Kassara River (IMWR-CRIM, 2006).

2.5.4 Phosphorus and nitrogen balance of Hour Al-Hawizeh

TP and TN load and export from Hour Al-Hawizeh were varied seasonally (Figures 11 & 14). During the study period, approximately 63% of TP enter Hour Al-Hawizeh were retained within the marshes. On the other hand, the TN export from Hour Al-Hawizeh was 1.3 times higher than its load. The annual net of TP and TN indicates that Hour Al-Hawizeh acts as a net sink for TP and net source for TN.

The retention of P and N fractions indicates that Hour Al-Hawizeh acts as net sink for DIP through the study period, while DIN balance had a slight release in summer (Figure 16). This was mainly because of the low amount of DIP that enters Hour Al-Hawizeh comparing to the DIN loading (Krah *et al.*, 2006). Plants uptake is possibly the main reason behind the high consumption of DIP and DIN in spring (Birch & Spyridakis, 1981; Van Geldermalsen, 1985; Yanagi 1999; Gophen, 2000; Okbah, 2005). The consumption of DIP and DIN by plants will transform it to POP and PON inside the plant tissues (Birch & Spyridakis, 1981; Okbah, 2005). In late summer, DOP exports increase while the DON is retained within Hour Al-Hawizeh. The increase of DOP exports from Hour Al-Hawizeh, especially in June and July 2006 (Figure 16), is mainly because the increases of the decomposition of dead plants (Gophen, 2000). In contrast to the DOP, I hardly detected any DON in the outlets during summer, while I noticed a release of DIN instead. This is mainly because the DOP produced via decomposition of dead organisms or organic matters are mainly colloidal and phospholipids, which can withstand most of the breakdown processes for considerably longer period (Mitsch & Gosselink, 2000; Wetzel, 2001). However, decomposition of DON (NH_4^+) can be readily oxidized to both NO_2^- and NO_3^-. Early fall, when the temperature drops slowly, some emerged plants and macrophytes grow for a short period (Alwan, 1992;

Yaqoub, 1992). For that reason, DIP and DIN are retained within the marshes and their export is low in the outlets. In winter, the amount of DP and DN entering the system was retained. This is mainly because their uptake by plants, especially the emergent species (Alwan, 1992). To the end of the year, TP balance kept retaining because there was no addition sources of P balance it loss. The high release of TN that appears in the export in November 2006 is mainly due to the external N input from the farms that expecting crop grow in early fall. The pre-wash as a preparation process to grow crop added a huge amount of N into the system and increase its export than its input. However, the release of TN in winter was mainly because of the there was no consumption of the amount of N entered the system (Alwan, 1992).

PP balance fluctuation shows that Hour Al-Hawizeh acts as sink for PP through the study period, except in July 2006 (Figure 16). This is mainly because of the low amount of PP entering Hour Al-Hawizeh either sedimented or was soluibilized into DP. Other studies found PP could transform in to DP, especially when the DP concentration within the aquatic system is not enough to supply the need of plant uptake (Krah *et al.*, 2006). In case of PN, the annual budget indicates that Hour Al-Hawizeh acts as a net source for PN. The monthly net of PN shows that there is release of PN in late summer and winter, while it retained in spring and late summer. The release of PN could be due to the re-suspension of the particulate matter (Gophen, 2000) close to the outlets or because of phytoplankton production (Okbah, 2005), while the retention could be due to the low loading or sedimentation. Measuring PN in total is not enough to trace the fluctuation of the PN in the system. More information on PON and PIN in the inlets and outlets will help to identify whether the Marshes are producing or releasing PN.

2.6 Conclusion

TP and TN budgets were calculated for Hour Al-Hawizeh for the period between May 2006 and March 2007. The limited budget and bad security situation that I faced during the study made me unable to measure the TP and TN concentrations in necessary to complete the data set. However, from the data that I successfully measured, I conclude the following:

1- The annual TP and TN load by the four Iraqi rivers: the Al-Mshereh, Al-Zubair, Um Al-Toos, Al-Husachi, was approximately 223.0 tons and 704.8 tons, respectively.

2- The Iraqi rivers are the main sources of TP and TN into Hour Al-Hawizeh, especially the Um Al-Toos and Al-Husachi rivers.

3- TP and TN load by precipitation is low.

4- The annual TP and TN export by the Al-Suwayb and Al-Kassara rivers were approximately 215.0 tons and 1151.0 tons, respectively.

5- Hour Al-Hawizeh acts as a net sink for TP for the period of May 2006 to March 2007.

The estimated f TP and TN budgets of Hour Al-Hawizeh in this study are the best I could do with the information available at this time. These estimates for TP and TN budget first in the Mesopotamian marshes. None of this work has been done before, even before the desiccation period.

Chapter 3

Phosphorus and nitrogen in Hour Al-Hawizeh

3.1 Introduction

Thirteen years after the desiccation of the Mesopotamian marshes, and the beginning of their re-inundation in April 2003, there is a hopeful expectation that these ecosystems will return to their natural condition. In this chapter, I will focus on variation in P and N, and their implication for the restoration process of Hour Al-Hawizeh specifically as a part of the Mesopotamian marshes. As it mentioned before, P and N are two of the most important nutrients for plant growth and they represent two of the most common limiting factors for the aquatic systems. Therefore, they tend to be the most limiting nutrients for the production of the organic matter via photosynthesis (Mitsch & Gosselink, 2000; Wetzel, 2001). Their variation also plays a role in the distribution and diversity of the phytoplankton, periphyton, and macrophytes (Dillon & Rigler, 1974; Al-Araji, 1988; Hassan, 1988; McCauley *et al*., 1989; Radwan, 2005; Panigrahi *et al*., 2007).

It is important from the restoration point of view to study P and N availability and distribution in the newly inundated marshes within Hour Al-Hawizeh. The main question that I will try to answer in this chapter is whether the newly re-flooded marshes will return to their previous condition. Normally, phytoplankton standing crop increases when there is enough nutrient supply (Dillon & Rigler, 1974). I will attempt to compare the TP and TN distribution and their correlation with phytoplankton biomass, represented by chlorophyll-*a*, in eight marshes within different histories.

The linear regression method, which has been used in the earlier studies in different wetland waters (Smith, 1982; Prairie *et al*., 1989; Kufel, 2001), will be used in this study to identify the relationship between chlorophyll-*a* concentration and TP and TN concentration in the selected marshes within Hour Al-Hawizeh in order to find what is the main factor control the phytoplankton production in these marshes.

3.2 Study site descriptions

Hour Al-Hawizeh is permanent fresh water marshes, dominated by emergent aquatic plants such as *Phragmites* and *Typha* (Stattersfield *et al*. 1998). This unique environment is a mix of permanent and seasonal open water, mudflats, and seasonally inundated plains (Partow, 2001).

Unlike the other marshes within the Mesopotamian region, a small part of Hour Al-Hawizeh remained wet even during the desiccation period. This part kept its original environmental features and therefore it is important for historical reasons. On the other hand, the damage caused by the war and desiccation processes left remarkable effects, especially in the central and southern parts of the Hour. For example, the construction of embankments disturbed the land sediment by moving it to create these embankments and still affects the flow of water. The Central Embankment is the longest one among these; it divides Hour Al-Hawizeh into two parts, north and south part. Other factors related to the war periods, e.g., burning the reeds beds and the use of the chemical weapons, also caused dramatic changes to Hour Al-Hawizeh.

3.3 The marsh complex within Hour Al-Hawizeh

3.3.1 Al-Udhaim marsh

Al-Udhaim marsh represents the natural, undisturbed marsh within Hour Al-Hawizeh because it did not suffer from the anthropogenic impacts that happened to the other marshes. The marsh remained wet because it receives water from Iran (Figure 17). Al-Udhaim marsh occupies an area of approximately 100 km^2. The marsh is dominated by *Potamogeton crispus*, *Najas minor*, and *Phragmites australis.*

3.3.2 Al-Souda north marsh:

Al-Souda north marsh is located in the northern west of Hour Al-Hawizeh (Figure 17). It occupies an area of approximately 70 km^2. During the desiccation period, the size of this marsh shrunk. This marsh receives water directly from the Al-Mshereh River (Figure 17). Al-Souda north marsh is connected to the Al-Udhaim marsh through several artificial channels. The vegetation cover of Al-Souda north marsh is mainly the submerged species *Potamogeton crispus* and *Ceratophyllum demersum*.

3.3.3 Um Al-Niaaj marsh:

Um Al-Niaaj marsh is the largest open water body within Hour Al-Hawizeh (Figure 17). Um Al-Niaaj marsh also shrunk in size during the desiccation period. It occupies an area of approximately 300 km^2. The main and direct water input to Um Al-Niaaj marsh comes from the Al-Zubair and Um Al-Toos rivers (Figure 17). This marsh is dominated by both submerged and emergent species including *Phragmites australis*, *Ceratophyllum demersum*, *Potamogeton leucenus*, and *Najas minor*.

3.3.4 Um Al-Warid marsh:

Um Al-Warid marsh is located in the north and west part of Hour Al-Hawizeh (Figure 17). This marsh was desiccated completely and the north part of it was transformed into agricultural fields. Um Al-Warid marsh occupies an area of approximately 50 km^2. The marsh has a direct water input from the Al-Husachi River (Figure 17). Um Al-Warid marsh is dense with *Potamogeton* sp., *Potamogeton crispus*, and *Phragmites australis*. The growth pattern of *Phragmites australis* communities makes it hard to delineate Um Al-Warid from the surrounding shallow marshes.

3.3.5 Al-Baydha marsh:

Al-Baydha marsh is located in the east of Hour Al-Hawizeh close to the Iraq-Iran border (Figure 17). It is isolated by three embankments. The marsh occupies an area of approximately 30 km^2. This marsh does not have a direct water input, but it depends on the water flow through the embankments from the north part of the Hour Al-Hawizeh. The constructed embankments affected the water quality of the marsh and had a negative impact on its water level and thus the density of its vegetation. Al-Baydha marsh is dominated by *Myriophyllum spicatum*. This marsh no longer supports emergent macrophytes.

3.3.6 Al-Souda south marsh:

Al-Souda south marsh is located in the center of Hour Al-Hawizeh (Figure 17). It is difficult to identify the boundary for this marsh because it is continuous with the surrounding marshes, Um Al-Niaaj and Umm Al-Warid. The accessible area of this marsh occupies an area of approximately 50 km^2. Al-Souda south marsh was burned during the Iraq-Iran was in 1980's, and much of its biodiversity was destroyed. Water flows from the north part of Hour Al-Hawizeh into this marsh through channels. Most of the drainage of Al-Souda south marsh water flows from Hour Al-Hawizeh through the Al-Kassara River (Figure 17). The dominant plant species of this marsh are *Phragmites australis* and *Najas minor*.

3.3.7 Lissan Ijerda and Majnoon marshes:

Lissan Ijerda and Majnoon marshes are located in the southern part of Hour Al-Hawizeh (Figure 17). They occupy an area of approximately 500 km^2. The southern part of Hour Al-Hawizeh is isolated by at least ten embankments. Lissan Ijerda marsh lies to the north of Majnoon marsh, receiving water through three openings in the Lissan Ijerda embankment. Majnoon marsh is surrounded by oil fields. The water flows from Lissan Ijerda marsh to Majnoon marsh and then flows from Hour Al-Hawizeh through the Al-Suwayb River (Figure 17). Lissan Ijerda marsh is dominated by *Phragmites australis* and *Najas minor*, while Majnoon marsh is dominated by *Phragmites australis* and *Myriophyllum spicatum*.

Material and methods

Fieldwork was carried out on a monthly basis starting in May 2006 to April 2007. The monthly variation of TP, TN, and chlorophyll-*a* were studied in eight marshes within Hour Al-Hawizeh (Figure 17, Table 8). The sampling stations were selected to represent different history of Hour Al-Hawizeh and divided into three groups regarding to the desiccation period: the first group includes Al-Udhaim marsh the undisturbed marsh, the second group includes the marshes that has water supply from rivers and partially dried, the third group include the southern marshes that completely dried and became a desert (Figure 17, Table 8).

Table 8: The longitude and latitude coordinates of the water sampling stations in eight marshes within Hour Al-Hawizeh from May 2006 to April 2007.

Sampling stations	Latitude and Longitude						Drying History
	North			East			
Al-Udhaim[1]	31°	41'	30"	47°	44'	0"	Undisturbed
	31°	41'	30"	47°	45'	0"	
	31°	41'	30"	47°	46'	35"	
	31°	41'	30"	47°	25'	1"	
Um Al-Niaaj[2]	31°	36'	0"	47°	35'	20"	Partially dried
	31°	36'	0"	47°	36'	25"	
	31°	36'	0"	47°	37'	20"	
	31°	36'	0"	47°	39'	16"	
Al-Souda North	31°	40'	23"	47°	40'	0"	
Um Al-Warid	31°	34'	47"	47°	31'	7"	Completely dried
Al-Souda South	31°	25'	15"	47°	36'	56"	
Al-Baydha	31°	22'	1"	47°	38'	46"	
Lissan Ijerda	31°	17'	27"	47°	34'	37"	
Majnoon	31°	7'	59"	47°	35'	33"	

[1] Due to the importance of Al-Udhaim marsh, four cross section stations were taken in this marsh.

[2] Due to the size of Um Al-Niaaj marsh four cross section stations were taken in this marsh.

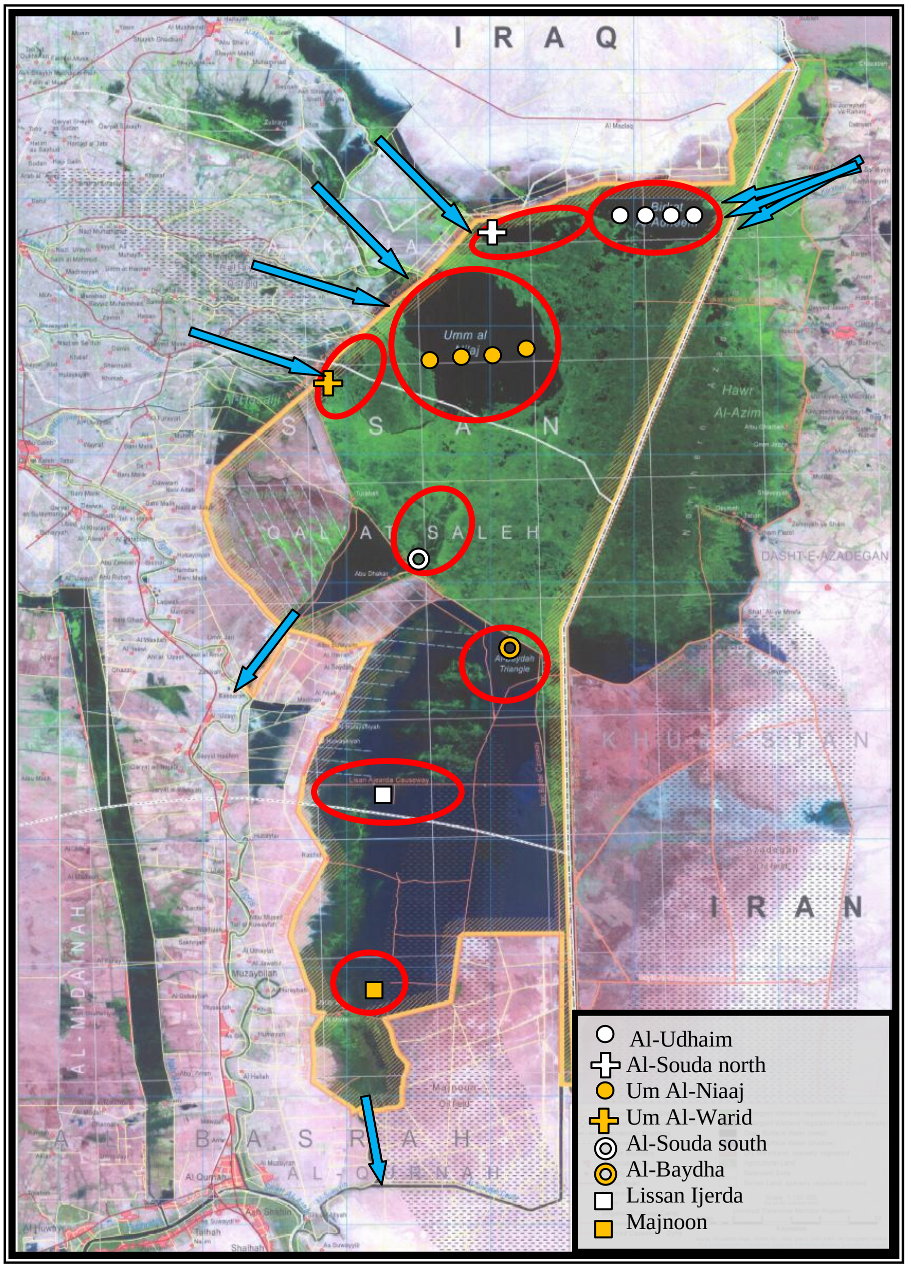


Figure 17: The sampling stations of the eight marshes within Hour Al-Hawizeh. Graph adapted from Partow, 2001. Stations latitude and longitude coordinates are listed in table 8.

At each station, triplicate water samples were collected from two depths using aVan Dorn bottle sampler. Surface water samples were collected approximately 30 cm deep, and the bottom samples were collected about 30 cm above the sediment surface. The physical and chemical parameters including water temperature (°C), salinity (ppt), dissolved oxygen (mg/l), and pH were measured using the WTW Multi-meter model 350i. Water depth (cm) was measured using an extendable ruler. Light penetration (cm) was measured using a Secchi disk (cm).

The water samples were filtered immediately in the field using pre-weighed GF/F 0.7 µm pore-size filters. The filtrate (500 ml) was transferred into translucent polyethylene screw-cap bottles. Bottles were pre-rinsed with the filtrate twice. Water sample preservation and handling is as described in chapter 2. Filters containing particulate matter were treated according to their respective analysis. Filters used to determine total PP and PN were treated as mentioned in chapter 2. However, filters used to determine chlorophyll-*a* were preserved by adding 5 ml of 1% magnesium chloride to each filter and were transferred immediately to dark amber scintillation vials and stored at 4 °C until the time of analysis (Stainton *et al.* 1977).

3.4 Laboratory analysis

Phosphorus and nitrogen fractions (PO_4^-, DP, PP, NO_2^-, NO_3^-, DN, and PN) were analyzed as described in chapter 2. However, there were some difficulties in the determination of DN concentrations. First, the water samples of June and July 2006 were lost. Second, because of analytical limitations it was difficult to estimate NH_4^+ concentrations in the water. On the other hand, $NH4^+$ was likely low to be detectable by methods at our disposal, i.e., less than 5 µg N/l. Previous studies reported low concentrations of NH_4^+ compared to the other N fractions, thus the DON was calculated as DN less NO_3^- and NO_2^-.

Chlorophyll-*a* concentrations were measured according to the monochromatric method described in Lorenzen (1967). Extraction occurred in the dark at -4 °C over night. The next day, the supernatant was allowed to reach room temperature and then transferred to a 1 cm quartz cell and measured in a Shimadzu spectrophotometer at 750 nm and 655 nm. The absorbance at 750 was used to correct the chlorophyll absorbance for turbidity.

3.5 Results

Comparison of water physical and chemical parameters, TP concentrations, TN concentrations, and chlorophyll-*a* concentrations in the surface water samples and near bottom water samples in the eight marshes within Hour Al-Hawizeh revealed no significant differences (paired *t*-test $P > 0.005$, Table 9). As a result, the data within the marshes were averaged to show one value per station.

Table 9: Water temperature, salinity, pH, dissolved oxygen, total suspended solid, TP, TN, and chlorophyll-*a* paired t test on surface water samples versus near bottom water samples in the eight marshes within Hour Al-Hawizeh.

	SD difference	t	df	P
Udhaim st. 1	10.60	-1.77	134	0.08
Udhaim st. 2	10.60	-1.77	134	0.08
Udhaim st. 3	11.55	-0.75	133	0.46
Udhaim st. 4	28.89	0.92	135	0.36
Um Al-Niaaj st. 1	7.12	-1.42	135	0.16
Um Al-Niaaj st. 2	11.10	0.44	136	0.66
Um Al-Niaaj st. 3	16.18	-0.68	135	0.50
Um Al-Niaaj st. 4	11.16	-1.27	135	0.21
Souda north	60.78	0.54	136	0.59
Um Al-Warid	16.12	0.48	136	0.64
Souda south	9.42	1.11	135	0.27
Baydha	7.99	0.43	137	0.67
Lissan Ijerda	15.47	-0.63	135	0.53
Majnoon	13.50	-1.30	100	0.20

3.5.1 The temporal variation of the water physical and chemical parameters in the eight marshes within Hour Al-Hawizeh

The temporal variations of water physical and chemical parameters varied seasonally (Table 11). During the study period, water temperature in Hour Al-Hawizeh ranged from 8.9 ºC to 33.0 ºC (Figure 18). The minimum value was found in January 2006, while the maximum value was recorded in August 2006 (Figure 18). The average values of salinity were higher in the southern marshes than in the northern marshes (Table 11). Dissolved oxygen (DO) average concentration was highest in the Un-Al-Niaaj marsh, 9.2 mg/l, whereas the lowest average concentration of DO was in the Al-Souda south marsh, 2.1 mg/l. A wide range of DO was observed in the Al-Souda south and Majnoon marshes (Table 11). The average values of pH were close among the marshes, with a very narrow range (Table 11). The average values of pH in the marshes ranged between neutral (7.2) to alkaline (8.2, Table 11). The average concentrations of total suspended solids (TSS) and light penetration (LP) in the marshes were varied among the marshes (Table 11). The highest average concentration of TSS and lowest LP were found in the Majnoon marsh, while the lowest average of TSS and high LP were in the Um Al-Niaaj marsh (Table 11). In addition, the average depth in the eight marshes within Hour Al-Hawizeh was close, but the water column fluctuation was varied between the marshes (Table 11). The highest water level fluctuation was found in the southern marshes rather than the northern marshes, especially the ones that have direct water input (Table 11).

Table 10: Average and range of monthly water temperature (WT, °C), salinity (ppt), dissolved oxygen (DO, mg/l), pH, total suspended solids (TSS, mg/l), light penetration (LP, cm), and water column depth (WCD, m) in the eight marshes within Hour Al-Hawizeh from May 2006 to April 2007.

		Udhaim	Souda north	Um Al-Niaaj	Um Al-Warid	Souda south	Baydha	Lissan Ijerda	Majnoon
WT	**average**	21.9	22.2	22.7	21.1	22.1	21.6	22.2	22.9
	range	10.0-31.9	10.1-31.5	10.9-31.6	9.4-31.1	9.8-31.1	9.6-31.5	9.9-33.0	10.7-32.2
Salinity	**average**	0.7	0.7	0.6	0.5	0.9	0.9	1.4	1.1
	range	0.5-0.9	0.5-1.0	0.4-0.9	0.2-0.8	0.6-1.3	0.6-1.1	1.0-1.8	0.9-1.3
DO	**average**	7.4	6.5	9.2	7.8	2.1	7.1	7.7	7.0
	range	5.2-10.6	1.7-9.2	6.1-11.8	5.4-11.1	0.3-7.9	4.8-9.0	4.1-10.0	0.9-11.5
pH	**average**	7.8	7.7	8.2	8.1	7.2	7.8	8.1	8.1
	range	7.5-8.3	7.3-8.0	7.9-8.6	7.9-8.6	6.6-7.6	7.5-8.1	7.5-8.5	6.7-8.5
TSS	**average**	1.6	2.3	1.5	10.3	4.6	3.0	4.8	70.5
	range	0.3-2.9	0.2-7.7	0.4-2.7	2.0-20.5	1.2-24.8	1.5-6.7	1.5-1.-1	0.6-219.3
LP	**average**	190	250	230	130	50	230	220	140
	range	170-220	200-310	210-250	50-250	50-180	190-300	130-340	30-80
WCD	**average**	2.1	2.6	2.4	2.3	2.4	2.4	1.7	1.5
	range	1.7-2.5	2.2-3.1	2.1-2.7	2.0-2.7	1.0-2.1	1.9-3.0	1.3-3.4	1.0-2.5

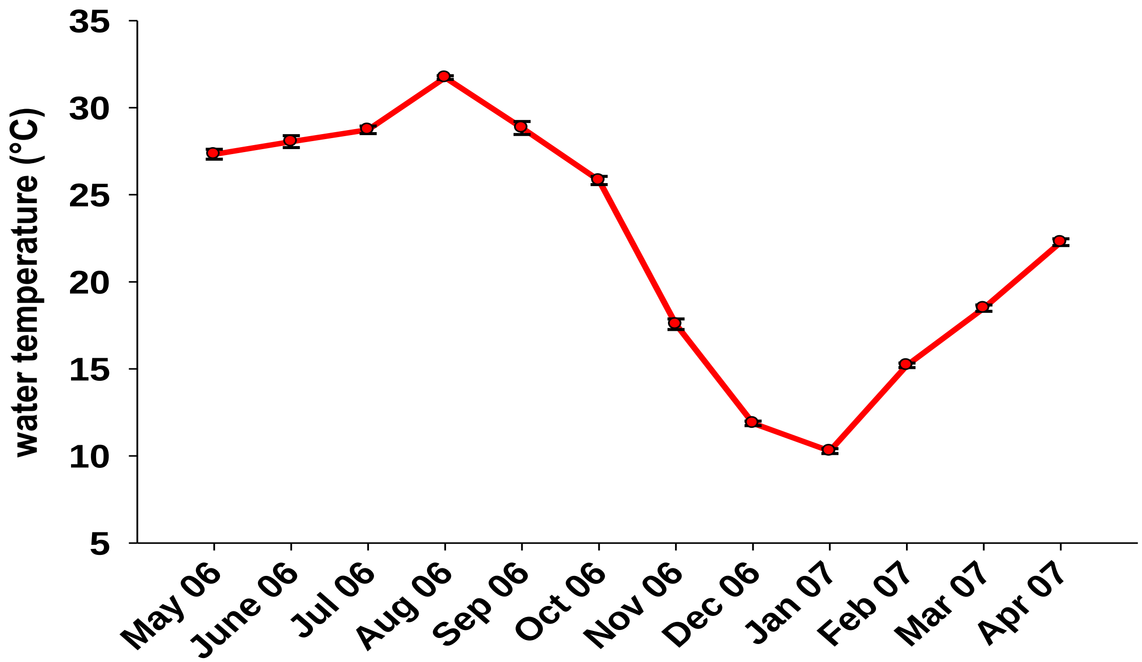


Figure 18: Monthly variation of average water temperature from the eight marshes within Hour Al-Hawizeh from May 2006 to April 2007, (error bars= standard error).

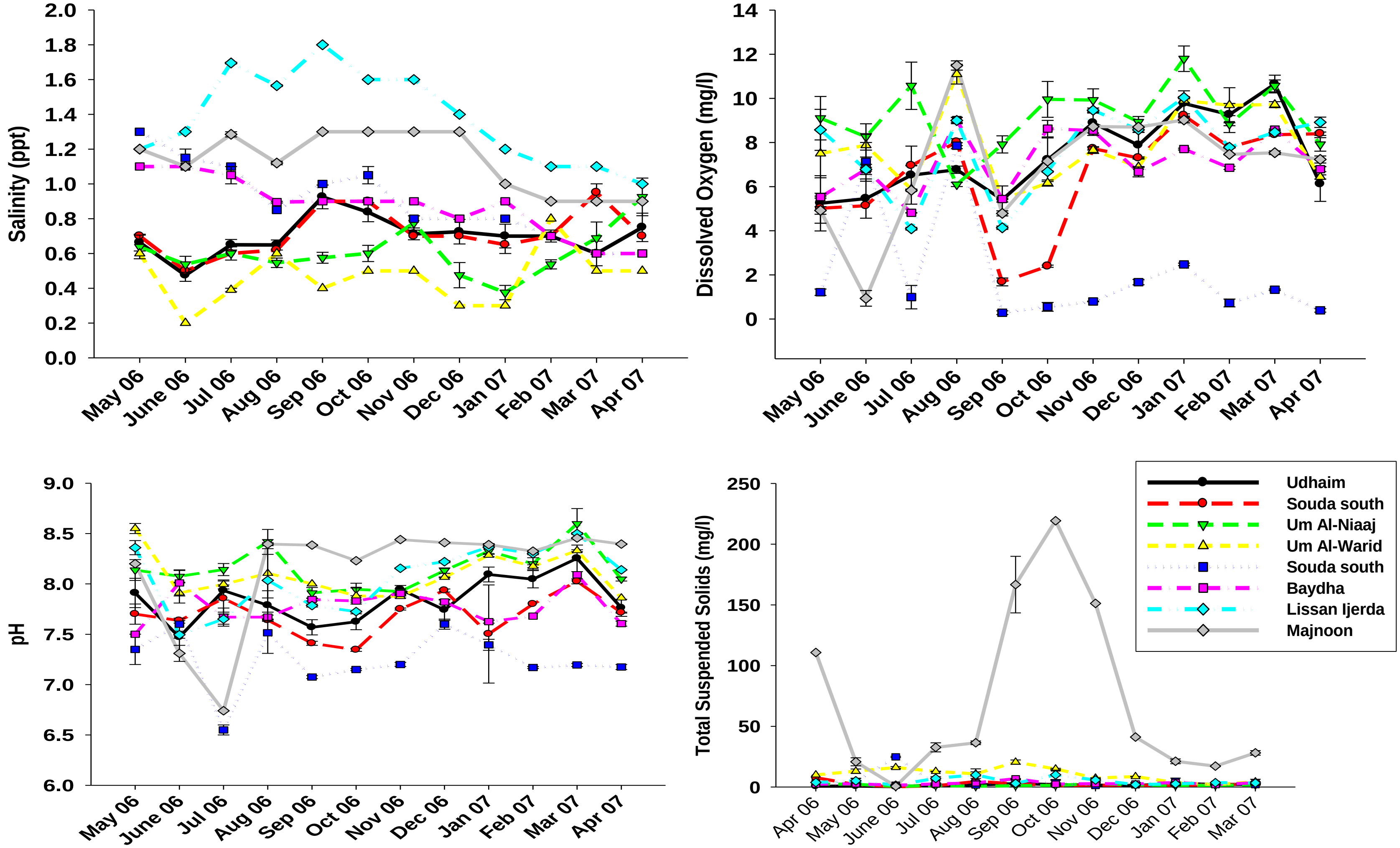


Figure 19: Monthly variation of salinity, dissolved oxygen, pH, and total suspended solids in the eight marshes within Hour Al-Hawizeh from May 2006 to April 2007 (error bars= standard error).

3.5.2 Phosphorus and nitrogen variation in Hour Al-Hawizeh

TP and TN concentrations in the eight marshes within Hour Al-Hawizeh underwent both spatial and temporal variation (Figures 20, 21, & 22). TP and TN were high during the summer and winter (Figures 20 & 21). The average concentrations of TP and TN in Hour Al-Hewaizah were 30.9 µg/l and 245.0 µg/l, respectively. The highest average concentration of TP was 68.4 µg/l recorded in Umm Al-Warid marsh, while the lowest average concentration of TP was 18.6 µg/l found in Al-Udhaim marsh (Table 12). The highest average concentration of TN was 711.7 µg/l found in Majnoon marsh, while the lowest average concentration was 123.6 µg/l found in Al-Souda south marsh (Table 12). Different patterns of P and N levels were found within the eight marshes of Hour Al-Hawizeh. P and N fractions were studied in each marsh (Table 12).

Table 11: Average and range of monthly P and N fractions (µg/l) in the eight marshes within Hour Al-Hawizeh from May 2006 to April 2007.

		Al-Udhaim	Al-Souda north	Umm Al-Niaaj	Umm Al-Warid	Al-Souda south	Al-Baydha	Lissan Ijerda	Majnoon
PO_4^-	Average	4.2	4.4	5.3	32.1	4.7	4.6	4.4	4.7
	Min	0.0	0.2	0.0	6.2	1.5	2.6	2.2	2.1
	Max	11.1	7.6	23.3	74.8	10.8	8.0	7.6	7.2
NO_2^-	Average	1.8	1.8	2.3	5.9	1.6	2.0	1.6	2.5
	Min	0.1	0.5	0.5	1.4	< 0.1	< 0.1	0.1	< 0.1
	Max	4.6	4.7	5.1	16.2	7.0	13.8	8.9	10.2
NO_3^-	Average	12.8	13.3	15.0	36.5	13.8	16.0	14.3	13.4
	Min	0.1	0.6	< 0.1	1.4	1.4	1.3	0.1	0.4
	Max	48.4	50.1	47.4	115.9	53.1	51.8	51.1	51.6
DOP	Average	11.7	16.7	14.1	27.9	20.1	18.6	15.2	20.9
	Min	1.3	0.9	0.9	4.7	2.0	1.0	1.9	2.4
	Max	48.5	67.2	67.0	165.5	117.2	80.6	83.2	71.4
DON	Average	69.1	94.6	98.5	80.8	84.0	72.6	110.5	79.6
	Min	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
	Max	288.2	571.9	483.8	390.9	421.8	328.7	622.5	346.8
PP	Average	2.6	3.1	3.4	8.5	1.8	2.0	5.2	9.8
	Min	1.0	1.3	1.7	1.1	0.5	0.0	2.2	0.6
	Max	4.7	12.0	9.3	16.1	3.2	4.6	10.7	20.8
PN	Average	91.5	90.7	85.1	129.5	66.9	92.6	181.7	628.2
	Min	31.0	29.0	33.8	31.0	23.0	23.0	59.0	188.0
	Max	181.0	174.0	178.0	230.0	167.0	267.0	483.0	1342.0
TP	Average	18.6	24.0	22.4	68.4	26.6	25.1	24.0	38.3
	Min	6.9	2.0	3.6	18.5	8.4	6.0	8.1	13.6
	Max	57.5	72.6	76.7	184.0	122.8	89.6	100.0	89.6
TN	Average	146.0	182.8	160.7	225.8	123.6	160.4	249.0	711.7
	Min	44.8	66.6	55.5	50.6	41.8	40.7	76.8	250.8
	Max	462.4	751.8	675.9	580.4	502.6	510.2	561.3	1352.0

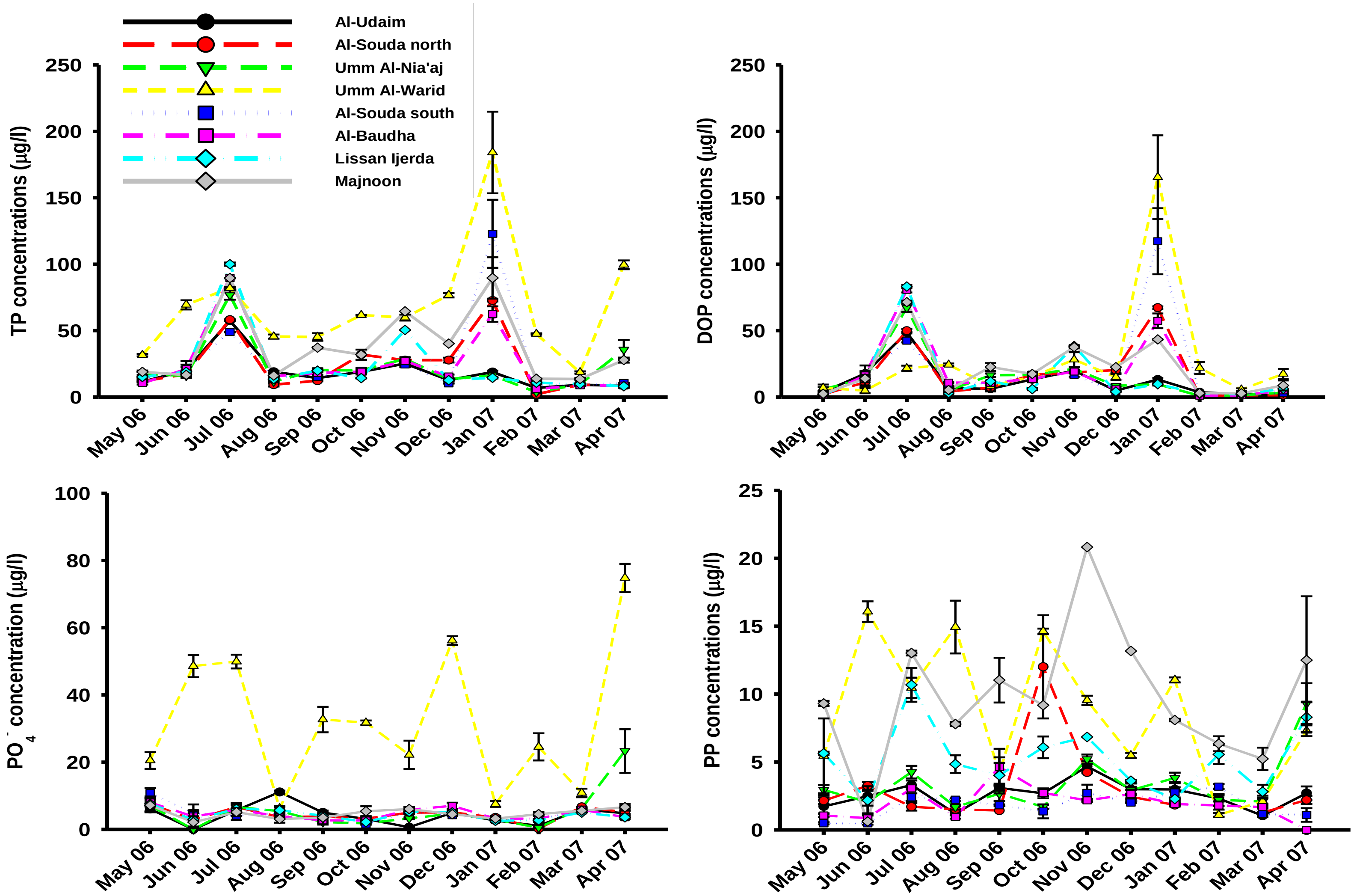


Figure 20: Monthly variation of total phosphorus concentrations in the eight marshes within Hour Al-Hawizeh from May 2006 to April 2007 (error bars= standard error).

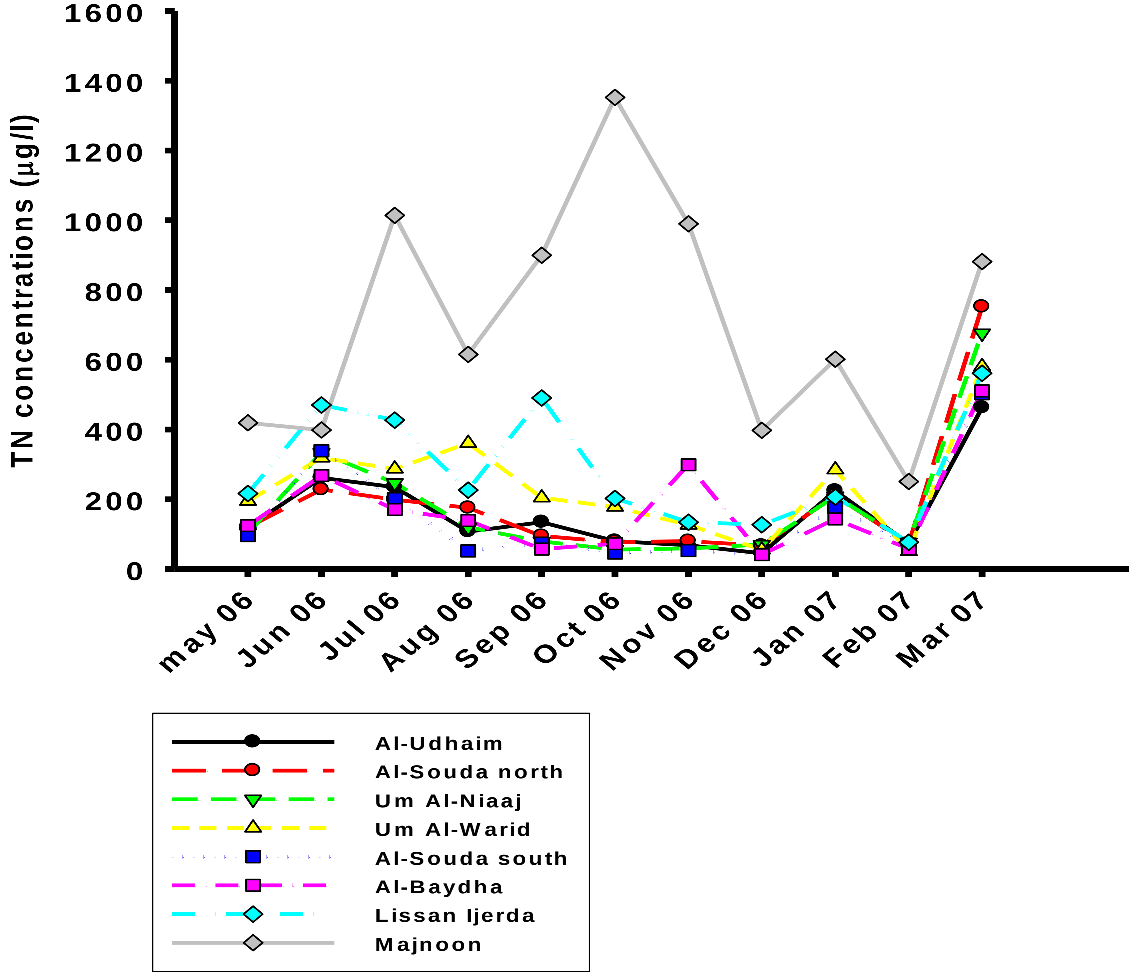


Figure 21: Monthly variation of total nitrogen concentrations in the eight marshes within Hour Al-Hawizeh from May 2006 to March 2007.

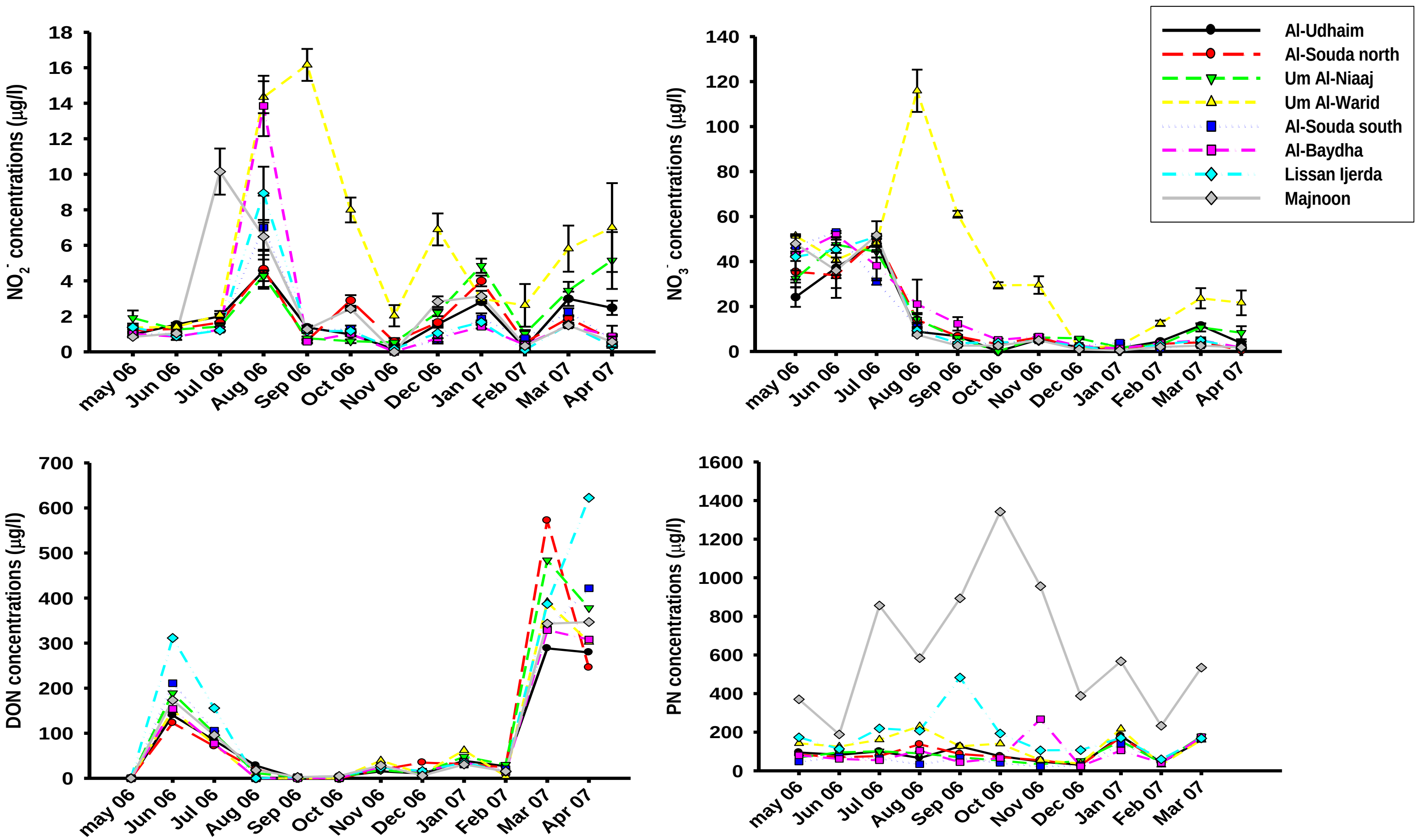


Figure 22: Monthly variation of nitrogen fractions in the eight marshes within Hour Al-Hawizeh from May 2006 to April 2007 (error bars= standard error).

3.5.3 Chlorophyll-*a* distribution in Hour Al-Hawizeh

Chlorophyll-*a* concentration in Hour Al-Hawizeh also underwent seasonal variation (Figure 23). Among all of the eight marshes, chlorophyll-*a* concentration was high during the summer and early fall then its concentration dropped during winter (Figure 23).

During the study period, the Majnoon marsh had the highest chlorophyll-*a* among the other marshes. Its concentrations ranged from 1.6 µg/l to 26.2 µg/l (Table 13). On the other hand, the Al-Baydha marsh had the lowest chlorophyll-*a* concentrations among the other marshes, its concentration ranged from <0.1 µg/l to 3.2 µg/l (Table 13).

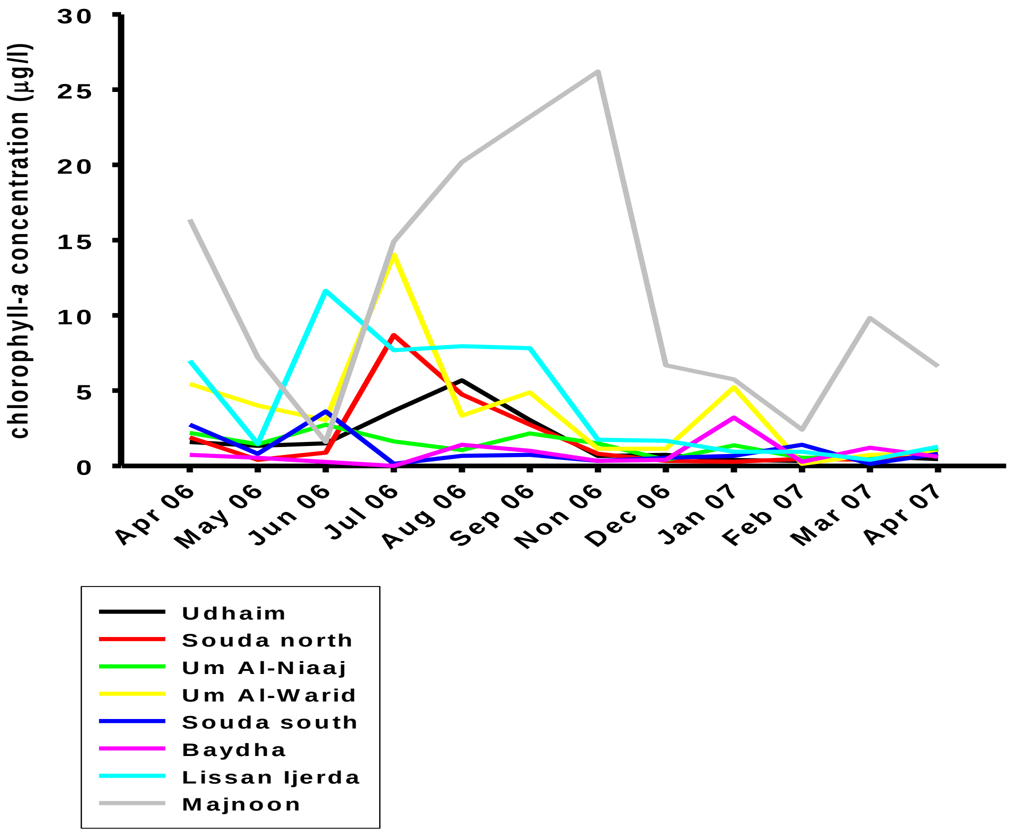


Figure 23: Monthly variation of chlorophyll-*a* in the eight marshes within Hour Al-Hawizeh from May 2006 to April 2007.

Table 12: Average and range of monthly chlorophyll-*a* concentrations (µg/l) in the eight marshes within Hour Al-Hawizeh from May 2006 to April 2007.

	Al-Udhaim	**Al-Souda north**	**Um Al-Niaaj**	**Um Al-Warid**	**Al-Souda south**	**Al-Baydha**	**Lissan Ijerda**	**Majnoon**
Average	1.7	1.9	1.4	3.7	1.0	0.8	4.2	11.7
min	0.3	0.3	0.4	0.1	0.1	<0.1	0.4	1.6
max	5.7	8.7	2.7	14.0	3.6	3.2	11.6	26.2

The correlations between chlorophyll-*a* and water physical and chemical parameters, as well as with TP and TN concentration, are differ among the eight marshes within Hour Al-Hawizeh. For example, in the Al-Udhaim marsh, chlorophyll-*a* variation was strongly influenced by the light penetration and dissolved oxygen rather than P and N concentrations (Table 14). However, P and N were the main factors that influenced the chlorophyll-*a* variation in the marshes that are close to the rivers (Table 14). P and N concentrations were also the main factors that correlated with the variation of chlorophyll-*a* in the Al-Souda south marsh (Table 14). However, in the southern marshes, chlorophyll-*a* varied according to both water quality parameters and P and N concentration (Table 14). Chlorophyll-*a* variation in the eight marshes were positively correlated to the water temperature (Table 14). It is worth mentioning that cholrophyll-*a* variation in the Al-Baydha marsh is not correlated to any water quality parameter or nutrient (Table 14).

Table 13: Correlation coefficients between chlorophyll-*a* and water temperature (WT), dissolved oxygen (DO), light penetration (LP), total phosphorus (TP), total nitrogen (TN), orthophosphate (PO_4^-), nitrite (NO_2^-), and nitrate (NO_3^-) in the eight marshes within Hour Al-Hawizeh.

	WT	DO	LP	TP	TN	PO_4^-	NO_2^-	NO_3^-
Al-Udhaim	0.7	-0.6	-0.8	0.0	-0.2	0.4	0.2	-0.1
Al-Souda north	0.6	-0.3	-0.7	-0.3	-0.2	-0.1	0.5	0.0
Um Al-Niaaj	0.5	0.1	-0.5	0.7	-0.4	0.3	-0.2	0.5
Um Al-Warid	0.6	0.4	-0.1	0.1	0.3	-0.4	0.5	0.8
Al-Souda south	0.4	-0.3	-0.2	0.1	-0.2	0.4	-0.3	0.6
Al-Byadha	-0.4	0.1	0.4	0.3	0.1	-0.3	-0.3	-0.3
Lissa Ijerda	0.8	-0.7	-0.4	0.5	0.1	0.4	0.3	0.4
Majnoon	0.4	0.1	-0.5	-0.1	0.8	0.3	-0.4	-0.2

The General Linear Model (GLM) in Systat was used to test the relationships between chlorophyll-*a* and TP and TN. The analysis shows a significant relationship between chlorophyll-*a* and TP (P= 0.006) and TN (P= 0.000). However, the relationship between chlorophyll-*a* and TN was stronger (Table 15, Figure 24). In addition, the GLM was also used to look at the effect of marsh and month on the variation of TP and TN. In this case the analyses revealed no significant relationships (Table 16 & 17).

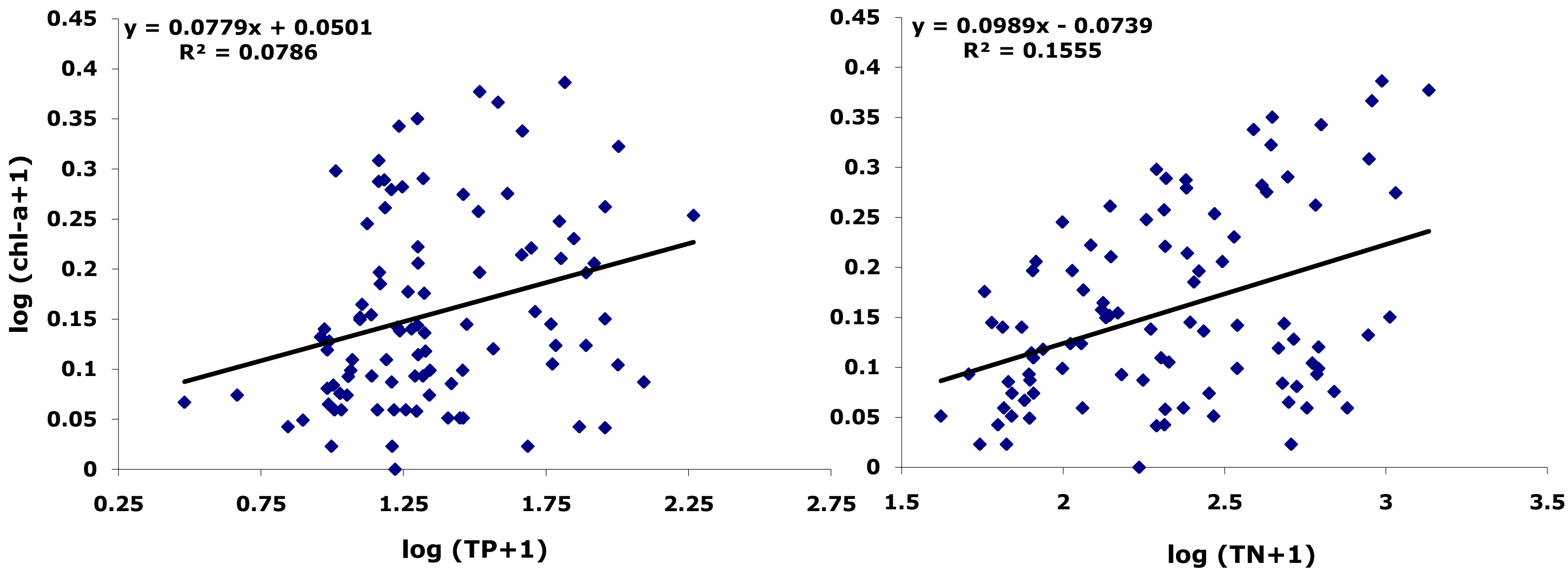


Figure 24: The relationships between chlorophyll-*a* and TP and TN concentrations in the eight marshes within Hour Al-Hawizeh.

Table 14: Regression tables of chlorophyll-*a* versus TP (A) and TN (B) in the eight marshes within Hour Al-Hawizeh. R^2 for chlorophyll-*a* versus TP is 0.078 and R^2 for chlorophyll-*a* vs TN is 0.155.

(A) Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P (2 Tail)
Constant	0.050	0.0390	0.000	.	1.298	0.197
Log TP	0.078	0.0280	0.280	1.000	2.832	0.006

(B) Effect	Coefficient	Std Error	Std Coef	Tolerance	t	P (2 Tail)
Constant	-0.074	0.056	0.000	.	-1.320	0.190
Log TN	0.099	0.024	0.394	1	4.160	0.000

Table 15: ANCOVA table for the relationship between chlorophyll-*a* and TP in the eight marshes within Hour Al-Hawizeh. In (A), the categorical variable (z) in this analysis is marshes and R^2 is 0.503. In (B), the categorical variable (z) in this analysis is months and R^2 is 0.361.

(A) Source	**Sum-of-Squares**	**df**	**Mean-Square**	**F-ratio**	**P**
Log TP	0.017	1	0.017	3.146	0.080
Marshes	0.046	7	0.007	1.243	0.290
Marshes*Log TP	0.031	7	0.004	0.818	0.575
Error	0.426	80	0.005		
(B) Source	**Sum-of-Squares**	**df**	**Mean-Square**	**F-ratio**	**P**
Log TP	0.084	1	0.084	11.042	0.001
Months	0.049	11	0.004	0.59	0.831
Months*Log TP	0.058	11	0.005	0.698	0.737
Error	0.548	72	0.008		

Table 16: ANCOVA table for the relationship between chlorophyll-*a* and TN in the eight marshes within Hour Al-Hawizeh. In (A), the categorical variable (z) in this analysis is marshes and R^2 is 0.481. In (B), the categorical variable (z) in this analysis is months and R^2 is 0.654.

(A) Source	**Sum-of-Squares**	**df**	**Mean-Square**	**F-ratio**	**P**
Log TN	0.002	1	0.002	0.441	0.509
Marshes	0.014	7	0.002	0.359	0.923
Marshes*Log TN	0.023	7	0.003	0.586	0.766
Error	0.445	80	0.006		
(B) Source	**Sum-of-Squares**	**df**	**Mean-Square**	**F-ratio**	**P**
Log TN	0.208	1	0.208	50.461	0.000
Months	0.048	11	0.004	1.066	0.401
Months*Log TN	0.038	11	0.003	0.847	0.595
Error	0.297	72	0.004		

Based on the history of the eight marshes within Hour Al-Hawizeh the *t*- test analysis shows that the three groups of marshes are different based on some water physical and chemical parameters, TP and TN concentrations. The analysis shows that the undisturbed marsh (Al-Udhaim marsh) is significantly different from the marshes that are close to the rivers and partially dried (the Al-Souda north, Um Al-Niaaj, Um Al-Warid marshes) in light penetration, TSS, and TP (Table 18). In addition, this marsh is also significantly different from the completely dried marshes (the Al-Souda south, Al-Baydha, Lissan Ijerda, and Majnoon marshes) in salinity, light penetration, TSS, TN, and chlorophyll-*a* (Table 18). The variation of TP and TN between the eight marshes indicates that the southern marshes are high in TN comparing to the undisturbed marsh (Figure 25). On the other hand, the partially dried marshes have the highest concentration of TP among the other marshes (Figure 25). As a result, the phytoplankton productivity as it presented by chlorophyll-*a* is higher in the southern marshes than the undisturbed marsh (Figure 25).

Table 17: Salinity (Sal), pH, dissolved oxygen (DO), water temperature (WT), light penetration (LP), total suspended solid (TSS), total phosphorus (TP), total nitrogen (TN), and chlorophyll-*a* (chl-*a*) paired t test on the three classes of marshes within Hour Al-Hawizeh: G1= the undisturbed marsh (Al-Udhaim marsh), G2= partially dried marshes, and G3= completely dried marshes.

		SD difference	t	df	P
Sal	G1 vs G2	0.12	3.03	11	0.010
	G1 vs G3	0.19	-7.04	11	0.000
	G2 vs G3	0.25	-7.07	11	0.000
pH	G1 vs G2	0.12	-3.40	11	0.010
	G1 vs G3	0.26	0.45	11	0.660
	G2 vs G3	0.22	2.73	11	0.200
WT	G1 vs G2	0.69	-5.51	11	0.620
	G1 vs G3	1.26	-0.80	11	0.440
	G2 vs G3	1.08	-0.61	11	0.550
DO	G1 vs G2	1.14	-1.12	11	0.250
	G1 vs G3	1.78	2.82	11	0.020
	G2 vs G3	1.31	4.89	11	0.001
LP	G1 vs G2	0.26	-1.23	9	0.230
	G1 vs G3	0.16	6.53	9	0.000
	G2 vs G3	0.27	4.85	9	0.001
TSS	G1 vs G2	2.28	-4.65	11	0.001
	G1 vs G3	17.86	-3.70	11	0.003
	G2 vs G3	17.1	-3.25	11	0.010
TP	G1 vs G2	19.28	-3.55	11	0.005
	G1 vs G3	15.77	-2.19	11	0.050
	G2 vs G3	11.71	2.89	11	0.020
TN	G1 vs G2	60.84	-2.55	11	0.030
	G1 vs G3	97.48	-6.19	11	0.000
	G2 vs G3	117.03	-3.83	11	0.003
Chl-*a*	G1 vs G2	1.63	-1.36	11	0.200
	G1 vs G3	1.76	-4.70	11	0.001
	G2 vs G3	2.25	-2.69	11	0.020

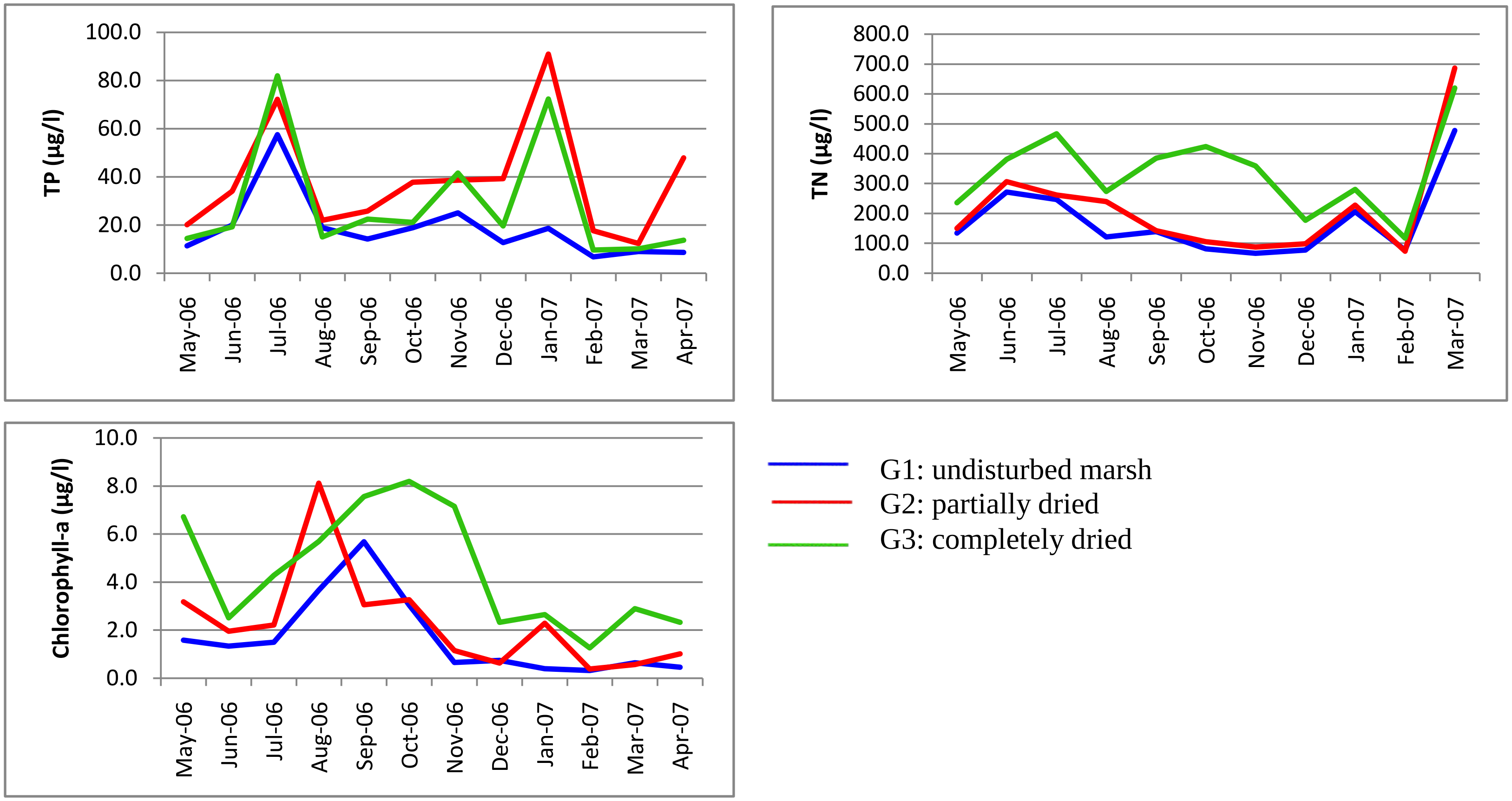


Figure 25: Monthly variation of TP, TN, and chlorophyll-*a* in the three marsh groups within Hour Al-Hawizeh showing the differences between each group.

Discussion

3.5.4 Water physical and chemical parameters variation in Hour Al-Hawizeh

The study revealed that there are no significant differences between water quality parameters, TP, TN, and chlorophyll-*a* measured in surface water samples and near bottom water samples as well as between locations within the same marsh, which reflects that Hour Al-Hawizeh water masses are well mixed by wave action and water currents.

Hour Al-Hewaizah waters exhibited similar temperatures across the marshes, the slight variations if the water temperature readings being attributable to the different times of the day (i.e. morning versus noon) when sampling took place. The water temperature in this study was within the range of values previously reported for Mesopotamian marshes (Al-Mousawi & Hussain, 1992; USAID, 2006).

Hour Al-Hewaizah waters are well oxygenated; only on a few occasions did I measure DO levels of less than 1 mg/l, which may have been due to error. DO in the eight marshes varies seasonally, attaining its maximum in winter when the water temperature cools down and decreases the decomposition rate. The minimum DO were encountered always in summer, mainly due to the rather elevated water temperature (>30 °C) and to a lesser extent to the extensive bacterial degradation of organic matter. The DO range in this study was wider than what was recorded in the previous studies (Al-Mousawi & Hussain, 1992).

The average pH value of Hour Al-Hewaizah was slightly alkaline (>7). This is mainly due to calcareous nature of the marshes sediments (Buringh, 1960; Antonin, 1984; Al-Mousawi &

Whitton, 1983). The pH values in this study were close to the ones reported in previous studies of Mesopotamian marshes (Al-Mousawi & Hussain, 1992).

Salinity variation in Hour Al-Hawizeh was influenced mainly by the seasons. Low salinity (< 0.5 ppt) was encountered in spring and winter, due to the increase of water level, which dilutes its concentration (Al-Saadi *et al*. 1981). On the other hand, relatively high salinity (>1.5 ppt) was recorded during the dry summer seasons, which is mainly due evaporation and lack of water supply during the dry season (Al-Mousawi & Hussain). In general, even the highest values within Hour Al-Hewaizah were low compared to the concentrations recorded in the previous studies for the Mesopotamian marshes (Al-Mousawi & Hussain, 1992). The reason for the higher salinity in the previous records is that most of the studies were done in Hour Al-Hammar which has tidal influence of brackish water from the Arab Gulf (Al-Mousawi & Hussain, 1992).

The amount suspended matter carried into Hour Al-Hawizeh influenced by two major factors, water currents and the re-suspension of the loosely bound surface sediments (Radwan, 2005, Panigrahi *et al*., 2007). Two major types of suspended particulate where observed were, abiotic (mainly silt and clay) and biotic (mainly plant litter or periphyton). The investigation indicates that most of the abiotic suspended matter found in the marshes closer to the rivers. The high water current in rivers disturb the surface sediment, especially during the flood season. On the other hand, biotic suspended matter was found in the marshes which are far from water inlets, and was detected during the growing season. High water current and dense plant growth in spring and high decomposition rate in summer, and soil erosion from the agriculture fields in winter are the main reasons to increase the suspended solids amount and influence its variation within Hour Al-Hawizeh (Al-Musawi & Hussain, 1992; Radwan, 2005). Low amounts of suspended solids were present in the marshes in low water flow condition and when plant growth was low. The extreme amount of suspended solids in the Majnoon marsh during the study period was mainly due to the dense vegetation growth in spring coupled with the rather shallow water depth in summer. The loosely bound sediment can easily be suspended. The TSS range in this study was close to one that found in the previous studies of the Mesopotamian marshes (Al-Aarajii, 1987; Al-Mousawi & Hussain, 1992).

It is worth mentioning that there were significant differences between the eight marshes within Hour Al-Hawizeh in terms of salinity, dissolved oxygen, light penetration, and TSS. This is strongly related to the to the desiccation history and water supply regime. The marshes which are close to the rivers had relatively low average salinity and high abiotic suspended matter, while the southern marshes had high salinity average and high biotic suspended matter.

3.5.5 The main factors influenced phosphorus and nitrogen variation in Hour Al-Hawizeh

Natural and artificial impacts likely influenced the TP and TN variation within Hour Al-Hawizeh. Rivers are the main natural factors influenced the TP and TN variation within Hour

Al-Hawizeh, especially in the marshes that have direct water supply (Al-Mousawi & Hussain, 1992). For example, the Al-Husachi River was the reason behind the high average of TP and TN concentrations found in the Um Al-Warid marsh (Figures 22 & 23). As I mentioned in the previous chapter, the Al-Husachi River is affect by chemical fertilizers, which were applied heavily during the study period, especially when the farmers prepare their farms for sowing crops (IMWR-CRIM, 2006). The Um Al-Toos River also adds a high amount of TP and TN into the Um Al-Niaaj marsh, but the reason that TP and TN concentrations were within the average range is because of the huge size and the high vegetation cover of the Um Al-Niaaj marsh. On the other hand, rivers like the Al-Mshereh could affect the variation of TP and TN in the Al-Souda south marsh. As I maintained in chapter 2, TP and TN loads by the Al-Mshereh River were very low compared to the other inlets. Therefore, rivers could have a negative or positive impact on recipient marshes with respect to nutrient inputs and variation. Vegetation cover is also a main factor that effects the variation of TP and TN within Hour Al-Hawizeh (Alwan, 1992). The density and variation of plants species among the seasons have a major impact on the TP and TN variation within the system. P and N variation will vary depend on the efficiency by removal plants and/or complexation (Al-Mousawi & Hussain, 1992; Hambright *et al.*, 1998; Zohary *et al.*, 1998; Radwan, 2005; Krak *et al.*, 2006). Constructed embankments are the main artificial factors influencing the P and N variation in Hour Al-Hawizeh. The field observations indicate that these embankments have a major influence on water currents and the circulation of water within Hour Al-Hawizeh. These embankments divide Hour Al-Hawizeh into many parts and isolate them from the whole marsh system. The embankments can slow water currents and thus lead to inefficient nutrient circulation. This will eventually affect the P and N transportation between the marshes. The inefficient P and N circulation could affect the vegetation cover and water quality in Hour Al-Hawizeh.

3.5.6 The temporal variation of phosphorus and nitrogen in Hour Al-Hawizeh

TP and TN concentrations exhibited different seasonal patterns among the marshes during the study period. Temporal variation of P and N fractions in the eight marshes within Hour Al-Hawizeh indicates that DIP and DIN concentrations were low in spring, which is mainly due to uptake by plants during the growing season (Gophen 2000; Al-Mousawi & Hussain, 1992; Okbah, 2005; Panigrahi *et al*., 2007). DOP and DON are present in high concentrations in late spring and reach their highest level in summer (Figures 22 & 23). This is likely because of the increased bacterial decomposition of dead phytoplankton and macrophytes, which is enhanced by the increase in temperature (Gophen, 2000). The increase in evaporation and decrease in water level also affects the TP and TN concentration in summer (Karh *et al*., 2006). In winter, the increase of TP and TN is mainly due to the low plant uptake (Al-Mousawi & Hussain, 1992). PP concentration was lower than the PN concentration within the marshes during the study period. This is could be due to two reasons: first, it might relate to the low amount of P-containing particles actually entering the system, or the suspended particulate matter in top sediment layer is nitrogen rich. It is well known that N content in living organisms is much higher than P and eventually, after the decay of these organisms, the released amount of N will be higher than P. Second, it could be that the rate of PP solubilization into DOP or DIP is higher than for PN solubilization into DOP or DON, which could be true because the concentration of DOP and DIP are also lower than DON and DIN.

In this study, an extremely high concentration of TP and TN was found in some of the marshes within Hour Al-Hawizeh. This is mainly because of the differences between marshes location and history. For example, TP and TN concentrations are likely influences by the rivers, especially in the marshes located close to water inputs. The differences between each inlet in nutrient eventually will have a significant impact on the vegetation cover in these marshes. For example, the high average concentration of TP and TN in Um Al-Warid marsh was likely due to the impact of the Al-Husachi River. And the high concentration of TN in the southern marshes, especially PN, was either due to the wide fluctuation of the water column depth within the seasons that led to re-suspension the top sediment layer, as I observed in the Majnoon marsh, or due to the density of plankton as I observed in the Lissan Ijerda marsh.

P and N concentrations in some of the pre-desiccation studies of the Mesopotamian marshes were within the range of P and N concentrations that I found during my study (Al-Lami, 1986, Al-Musawi & Hussain, 1992; Al-Rikaby, 1992; Al-Zubaidi, 2006). On the other hand, higher values of P and N fractions were found in different pre-desiccation studies (Maulood *et al.*, 1981 &1984; Anon, 1985; Al-Timimi, 1992). In addition, concentrations of P and N fractions in my study were close to some of the recent studies that were done in the Mesopotamian marshes after re-flooding (Al-Imarah *et al*., 2006; USAID, 2006). However, some of the recent studies indicated higher values of P and N within the Mesopotamian marshes than found in this study (Richardson *et al.*, 2005; Richardson & Hussain, 2006, USAID, 2006).

3.5.7 Chlorophyll-*a* variation in Hour Al-Hawizeh

The difference in the seasonal variation of the chlorophyll-*a* between the eight marshes within Hour Al-Hawizeh was likely dependent on their location and vegetation cover. It may be also associated with the ability of these marshes to provide appropriate conditions for phytoplankton growth. The temporal variations of chlorophyll-*a* in Hour Al-Hawizeh were strongly influenced by the water temperature. The highest concentration of chlorophyll-*a* was observed in summer (July to September 2006) reflecting the highest peak of phytoplankton mass (Zohary *et al*., 1998; Benson-Evans *et al*., 1999). Phytoplankton can tolerate a certain temperature; when the water temperature becomes greater than 35 °C, phytoplankton growth declines (Alwan, 1992). In fall, the slight decrease of the temperature stimulates phytoplankton to grow again and may have led to the increase the chlorophyll-*a* (Alwan, 1992). This situation does not last long, and biomass decreases when the temperature drops to <10 °C in winter. On the other hand, the variation of chlorophyll-*a* was influenced by the availability of TP and TN within the marshes. For example, the high amount of chlorophyll-*a* found in the Majnoon and lissan Ijerda marshes is related to the high concentrations of TN. On the other hand the low concentrations of TP and TN in Al-Baydha marsh could be a reasons behind the low amount of chlorophyll-*a* in this marsh. Light penetration is also a main factor that could affect the variation of chlorophyll-*a*. Turbid water conditions affect the light penetration which is very important for phytoplankton growth, and thus decrease the amount of chlorophyll-*a* (Alwan, 1992; Yaqoub, 1992; Radwan, 2005). In this study, the average concentrations of chlorophyll-*a* in Hour Al-Hawizeh were low compared to other studies done in the Mesopotamian marshes and other similar wetlands (Zohary *et al*., 1998; Gophen, 2000; Radwan, 2005; Al-Zubaidi *et al*, 2006).

Chlorophyll-*a* variation in the eight marshes responded differently to TP and TN concentrations. In this study, there was relationship between chlorophyll-*a* and TP and TN, but this relation is relatively weak. This is mainly because the differences between TP and TN within in different parts of Hour Al-Hawizeh (IMWR-CRIM, 2006). Low concentrations of TP and TN and poor water quality conditions could also affect the strength of the relationship. Different studies found significant relationships between phytoplankton biomass (chlorophyll) and P and N concentrations (Gophen, 2000; Kufel, 2001; Panigrahi *et al.*, 2007). Light limitation or grazing could also affect the relationship between chlorophyll-*a* and TP and TN. The study by Radwan (2005) found chlorophyll-*a* concentrations were correlated to water quality parameters (water temperature, transparency, and dissolved oxygen) and P. In Kufel (2001) study, the concentration of chlorophyll-*a* was not correlated to either P or N concentration in the mesotrophic Great Masurian Lakes, while chlorophyll-*a* was correlated to the P and N concentration in the eutrophic lakes. Zooplankton grazing could also be a reason for poor chlorophyll-nutrient relationship (Kufel, 1999, Kufel, 2001). Phytoplankton biomass is one of the factors that represent the productivity situation of aquatic systems. As phytoplankton component, chlorophyll-*a* can reflect the productivity in Hour in different marshes within Hour Al-Hawizeh. In addition, chlorophyll-*a* can also reveal the restoration process of this Hour. The undisturbed marsh is also low in chlorophyll-*a*, which means low productive. This is mainly because of the low concentration of P and N in this marsh. The high amount chlorophyll-*a* in some of the completely dried marshes reflect the success of restoration process, especially in the Lissan Ijerda and Majnoon marshes. This is mainly because these marshes have high concentrations of TP and TN. Rivers also affect the restoration process of the marshes that located close their input by the amount of P and N load. Although TP and TN were available in the Al-Baydha marsh, the amount of chlorophyll-*a* was so low which slow the restoration of this marsh. It is hard to judge whether the low concentrations of chlorophyll-*a* in the Al-Baydha marsh was related to the poor water quality conditions or to the lack of P and N. This issue could be an interesting point to focus on in the future studies.

3.6 Conclusions

1. There are no significant differences between the water quality parameters, TP, TN, and chlorophyll-*a* between surface water samples and near bottom water samples.

2. The temporal variation of water temperature and pH, in the selected marshes within Hour Al-Hawizeh showed no significant differences; however, there were significant differences in salinity, dissolved oxygen, light penetration, suspended solids, TP, TN, and chlorophyll-*a* between eight marshes within Hour Al-Hawizeh.

3. The temporal and spatial variations of TP and TN concentrations within Hour Al-Hawizeh were likely influenced by natural (water input, vegetation cover) and artificial (constructed embankments) impacts.

4. There was a relationship between chlorophyll-*a* and both TP and TN concentrations in Hour Al-Hawizeh. However, the relationship between chlorophyll-*a* and TN concentration was stronger than TP.

5. The success of the restoration process of Hour Al-Hawizeh varied among the different marshes according to the hydrology and the drying history of the marsh.

6. The differences in water quality parameters, TP, TN, and chlorophyll-*a* among the eight marshes within Hour Al-Hawizeh suggest that Hour Al-Hawizeh is not a one homogeneous system. The constructed embankments divide Hour Al-Hawizeh into

several parts and isolate some of these parts completely from being a one active ecosystem as it should be.

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